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An Analysis of Cost Implications of Accomplishing Direct Support Maintenance Tasks for the Truck, 1/4-Ton, M151 Series at the Organizational Maintenance Level

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This study proposes that allocation of maintenance responsibilities should be based on the particular equipment being supported as opposed to applying one concept to all commodities. This study develops a methodology for analysis of individual items of automotive materiel. The vehicle for analysis is the M151A1 ¼-ton truck. The intent of the model and methodology is to permit analysis of more complex automotive items in order to obtain a more optimum allocation of maintenance responsibility.

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AN ANALYSIS OF COST IMPLICATIONS OF ACCOMPLISHING DIRECT SUPPORT MAINTENANCE TASKS FOR THE TRUCK, ¼-TON, M151 SERIES AT THE ORGANIZATIONAL MAINTENANCE LEVEL

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

by

DONALD C. FISCHER, JR., MAJ, USA
M.S., United States Air Force Institute of Technology, 1972

Fort Leavenworth, Kansas
1975

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ABSTRACT

An Analysis of Cost Implications of Accomplishing Direct Support Maintenance Tasks for the Truck, ¼-Ton, M151 Series at the Organizational Maintenance Level

MAJ Donald C. Fischer, Jr.

27 May 1975

119 pages

The study tests the hypothesis that if responsibility for replacement of engines, transmissions, clutches, and steering gear assemblies for the M151 ¼-ton truck series was moved to organizational level, there would be significant cost savings. The history of automotive maintenance management is examined. Tool and training cost implications are investigated. A computer simulation generates direct support maintenance requirements, costs, and tests results for statistical significance.

Title: An Analysis of Cost Implications of Accomplishing Direct Support Maintenance Tasks for the Truck, ¼-Ton, M151 Series at the Organizational Maintenance Level

Researcher: MAJ Donald C. Fischer, Jr., OD

ABSTRACT

Problem

The general problem studied was the feasibility of moving direct support maintenance responsibilities forward to the organizational maintenance level. The current concept relies on centralization of skills and capital equipment such as tools and test equipment. This is a viable concept when the price of facilities is high relative to labor. In recent years, however, labor has become an extremely high priced commodity and using people in such tasks as driving to maintenance units frequently to deliver and pick up equipment is inefficient. Thus, when equipment is high priced, complex, cumbersome, and requires highly specialized skills such as certain missile system support equipment, a central maintenance facility is economical. If, however, tools are cheap versus the cost of people, then perhaps the tools should be proliferated to increase the productivity of people.

Flexibility, then, is required in the study of the problem of providing direct support. This study proposes that allocation of maintenance responsibilities should be

based on the particular equipment being supported as opposed to applying one concept to all commodities. This study develops a methodology for analysis of individual items of automotive materiel. The vehicle for analysis is the M151A1 ¼-ton truck. The intent of the model and methodology is to permit analysis of more complex automotive items in order to obtain a more optimum allocation of maintenance responsibility.

Two research questions were examined:

1. What are tool and equipment costs incurred by moving responsibility for replacement of engines, transmissions/transfer assemblies, clutches, and steering gear assemblies forward to the using organization for the M151A1 ¼-ton truck?

2. What are the costs associated with providing additional skills at the organizational level to permit replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies?

The research hypothesis examined was:

If responsibility for replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies was shifted from direct support to organizational maintenance level, there would be a significant reduction in direct support maintenance costs.

Methodology

The maintenance allocation chart for the M151 series of trucks was reviewed to determine what component replacement was a direct support responsibility. The engine, transmission/transfer assembly, clutch, steering gear, and oil pump must be replaced by the direct support unit. Oil pump replacement was not examined since the data base for the study showed that for 108 vehicles operated over 5,000,000 miles, no oil pump replacements were recorded.

Tool Costs. Tool costs were estimated by reviewing the direct and general support maintenance manual to determine what tools are required to replace the above components. The organizational maintenance shop set (No. 2 Common) was used to determine if those tools are on hand at organizational level. The Army Master Data File was used to determine the price of tools that would have to be provided if major component replacement responsibility for the M151 was given to the organizational level.

Training Costs. The programs of instruction for MOS 63H20, Automotive Repairman (direct and general support) and MOS 63C20, Tracked Vehicle Mechanic (organizational) were compared to determine what field maintenance training would have to be given organizational mechanics to permit them to replace M151 series major components.

Variable Costs. A computer simulation was used to simulate direct support maintenance requirements generated by ¼-ton trucks organic to a mechanized infantry battalion. Models for direct and indirect costs were developed to describe the current maintenance concept where vehicles are taken to the direct support unit for repair and the proposed concept where component replacement would be done at and by the organizational level.

Current concept model:

ATOTCST = (OGPRPTM + TRANSTM + DSMNTM)*6.48 + APOLCST

where

ATOTCST = Total maintenance costs generated by the current concept (Concept A)

OGPRPTM = Time required to prepare a vehicle for acceptance by the direct support unit

TRANSTM = Time required to transport the disabled vehicle to and from the direct support unit

DSMNTM = Time required to replace the component

6.48 = Hourly labor rate (USAREUR, 1974)

Proposed concept model:

BTOTCST = DSMNTM*6.48

where OGPRPTM and TRANSTM are assumed to be zero due to repairs being accomplished by the owning unit.

Results

Tools. Tools required by the organization consisted of the engine/transmission removal sling. An optional item would be the automotive hoist. Estimated costs are $150-$300 per battalion.

Training. Additional training would be 35 hours at a cost of approximately $191 per student (MOS 63C20). For a mechanized infantry battalion currently authorized 7 such mechanics, the cost would be approximately $1,337.

Variable Costs. The computer simulation and the statistical test showed that cost savings under the proposed concept were statistically significant. Comparison of these savings to tool and training costs showed that the additional investment would have a high payoff, especially in situations where there was a large distance between the user and the support unit or where conditions increased normal maintenance requirements.

ACKNOWLEDGEMENTS

The author extends his sincere appreciation to Dr. George Rice, Lieutenant Colonel Eugene Small, and Major Edward Kelley for the time and knowledge provided in their capacity as the advisory committee; to Major William Allard, USAR, for his invaluable assistance in developing the computer simulation program; and to Mrs. Beverly Cleaver, the typist, for her indispensable contribution to the study.

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CHAPTER 1

THE PROBLEM

INTRODUCTION

There is a need to reduce the number of people involved in logistic support. The personnel situation today consists of fixed personnel ceilings coupled with pressure to increase combat power. The result is a need to increase the ratio of combat spaces to support spaces. For example, the Defense Appropriations Bill for fiscal year 1975 calls for a reduction of 12,500 spaces in overseas strength by 31 May 1975. This is half of the 25,000 overseas reductions required by the Senate. Congress restored a Senate deletion of $61,000,000 intended to give taxpayers the benefit of savings in support and headquarters personnel provided these funds would be used to increase combat strength.[1] Thus, personnel reductions must occur in the logistics structure.

More importantly, combat effectiveness requires the leanest possible support structure for economy, simplicity, and to reduce targets created by large support complexes. Large distances between maintenance support and using units were typical in Vietnam and currently exist in Europe, particularly for non-divisional units. The existence of several logistics echelons increases system complexity,

capital equipment requirements, personnel overhead, and, above all, vulnerability. LTG Walter Woolwine, Commandant of the Industrial College of the Armed Forces and former Director for Logistics (J4), Organization of the Joint Chiefs of Staff, has pointed out increased costs of logistics support caused by the destructive power of modern weapons. He calls for increasing the capability to absorb damage "by reducing the vulnerability of the system through reduction or elimination of the traditional support structure at every echelon."[2]

Finally, personnel costs require elimination of people wherever possible. Logistic support units have administrative overhead not directly related to particular functions, but necessary because of the personnel management structure and requirements to provide for the security and welfare of people. Thus, we should eliminate separate units where possible. It is also reasonable to expect greater productivity per individual with the higher salaries, better working and living conditions, and longer personnel retention associated with the volunteer army.

This study will examine the feasibility of increasing maintenance responsibilities at the battalion level by allowing battalion maintenance organizations to replace major components of the ¼-ton truck, M151 series. These tasks are now performed by divisional and non-divisional direct support maintenance units. The structure has performed well, but the author's experience indicates that new approaches should at least be tested. We must relate our support structure to

constant principles and functions and not as RADM Henry Eccles has said, to "administrative decisions, operational procedures and terminology . . . which . . . can be changed by a simple executive order."[3] This study will consider one aspect of the job of maintenance, the feasibility of an alternative approach and a model for further examination of our organization for automotive maintenance support.

BACKGROUND

The current army maintenance concept is based on categories of maintenance. Organizational maintenance is maintenance authorized to be performed by personnel at unit level on organic equipment.

The direct support maintenance category involves repairing assemblies and end items for return to user organizations. As far as possible repair is accomplished on site. With some exceptions, direct support units provide services for all material commodities in the hands of the user. The direct support unit maintains the operational readiness float and receives unserviceable assemblies for evacuation when necessary.

The general support and depot maintenance categories involve operations to support theater and overall inventories respectively.[4]

Tasks to be performed at the organizational maintenance level are determined by the organization mission, equipment complexity or bulk, and the unit location and

readiness requirements. Maintenance allocation charts for items of equipment show maintenance tasks to be performed in each maintenance category.[5] In the division, direct support maintenance service is provided by the division maintenance battalion. Forward support companies from the maintenance battalion support division brigades. Non-divisional units are supported by corps or theater army support command maintenance battalions on an area basis.

There is a need to examine this concept. Combat situations may require that skills and components be located forward. This can be accomplished by temporarily attaching direct support personnel to the user organization. However, attachment may not be feasible if there are unexpected requirements. In the case of non-divisional direct support units supporting large areas, attachment of organic personnel to supported units may make it impossible to provide support to other unit customers. For example, the Vietnam environment, involving long, insecure lines of communication, made resupply and on-site maintenance support very difficult.

Precedents exist for deviating from the conventional maintenance structure. Air defense battalions, engineer construction battalions and engineer special companies are provided with organic direct support capability for low density or unique equipment necessary to accomplish their missions. Support for other commodities is provided by non-divisional direct support units.[6] For example, a NIKE-HERCULES missile battalion has a direct support platoon that

performs direct support maintenance on missile system launcher and radar components and on tactical power generating equipment.[7] A non-divisional unit provides direct support services for the NIKE battalion automotive equipment. It is likely that direct support maintenance for organic trucks and other automotive items could be performed within the battalion.

Similarly, the organic skills and equipment available to an engineer construction battalion to enable it to repair items such as cranes, scoop loaders, and bulldozers are comparable to skills required to maintain automotive equipment.

Studies of aviation direct support maintenance concepts have shown that operational readiness of aviation units is improved by providing an "integrated direct support maintenance" capability.[8,9] A study by the American Power Jet Company suggests that there is potential for reduction of personnel and administrative overhead by incorporating direct support personnel into the using organization and eliminating aviation direct support units.[10]

PROBLEM

The existing direct support maintenance concept makes maximum use of capital facilities and specially trained personnel by having single divisional and non-divisional direct support units support several organizations. Use of much capital equipment must be centralized because of

complexity, the need for specialized training, size, and investment cost. The Land Combat Support System used to maintain various missile systems is an example. The direct support concept also reduces component stockage at the organization which preserves using unit mobility and reduces inventory costs. On the other hand, it could be possible to offset transportation and associated personnel costs by proliferating capital equipment that has become relatively inexpensive when compared to the cost of people engaged in tasks such as driving extended distance to deliver a vehicle for repair.

Therefore, although location of direct support maintenance skills and responsibility outside the using organization is generally justified, there is a potential for selective decentralization of maintenance responsibility for individual line items.

PURPOSE OF THE STUDY

This study examines the history and underlying assumptions of automotive maintenance. A methodology is developed to analyze cost implications of moving direct support maintenance responsibilities for automotive equipment forward to the using organization. Emphasis is placed on individual items. The vehicle for analysis in this study is the ¼-ton truck, M151 series.

A computer simulation is used to compare variable costs associated with direct support maintenance under the

current concept of having major component repair performed by a divisional or non-divisional direct support unit versus having such repair performed at the organizational maintenance level. Fixed costs such as tool and test equipment costs and costs associated with additional personnel and training are also examined.

Research questions to be investigated in connection with tool and test equipment and training costs are as follows:

Research Question 1

What are tool and equipment costs that would be incurred by moving responsibility for replacement of engines, transmissions/transfer assemblies, clutches, and steering gear assemblies for the M151A1 ¼-ton truck forward to the using organization?

Research Question 2

What are the costs associated with providing additional skills at the organizational level to permit replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies for the M151A1 ¼-ton truck?

Research Hypothesis

The research hypothesis to be tested using a computer simulation is:

If responsibility for replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies for the M151A1 ¼-ton truck was shifted from direct support to organizational maintenance level, there would be a significant reduction in direct support maintenance costs.

CHAPTER 1

FOOTNOTES

1. Congressional Quarterly Weekly Report, Vol. XXXII, No. 39, 28 September 1974, p. 2631.

2. LTG Walter J. Woolwine, "A Logistics Perspective," Army Logistician, Vol. 7, No. 2 (March-April, 1975), p. 44.

3. Henry E. Eccles, RADM (Ret.), Logistics in the National Defense, Harrisburg, Pennsylvania: The Stackpole Company, 1959, p. 11.

4. U. S. Department of the Army, HQ, Department of the Army, Field Manual, FM 100-10, Combat Service Support (Washington: Government Printing Office, 30 March 1973), pp. 10-5, 10-6.

5. FM 100-10, p. 10-5.

6. U. S. Department of the Army, HQ, Department of the Army, Field Manual, FM 29-2 with Change 1, Organizational Maintenance Management (Washington: Government Printing Office, 26 August 1971), pp. 13-1, 13-2.

7. U. S. Department of the Army, HQ, Department of the Army, Tables of Organization and Equipment, TOE 44-536H with Change 4, Headquarters and Headquarters Battery, Air Defense Artillery Battalion, NIKE-HERCULES (Washington: Government Printing Office, 29 March 1972), pp. 11-12.

8. U. S. Department of the Army, U. S. Army Logistics Evaluation Agency, Army Aircraft Maintenance Structure Study (Washington: Office of the Deputy Chief of Staff for Logistics, HQDA, October 1973), p. x.

9. American Power Jet Company, Comparative Analysis of Army Aviation Maintenance Concepts (Washington: Office of the Deputy Chief of Staff for Logistics, HQDA, September 1967), pp. 1-3 through 1-16.

10. American Power Jet, p. 1-5.

CHAPTER 2

REVIEW OF THE LITERATURE

OVERVIEW

This chapter will review the development of the army's organization for automotive maintenance to provide a basis for examining the alternative of moving tasks to the using organization level that are presently performed by direct support units. The following will be addressed:

1. Development of the automotive maintenance concept.
2. Representative studies.
3. Apparent assumptions and basis for examination.

DEVELOPMENT OF THE AUTOMOTIVE MAINTENANCE CONCEPT

Early Organization for Maintenance

Mechanization is a recent development in warfare. In 1914, there was no provision for maintenance at division level.[1] Truck transport, a responsibility of the Quartermaster Corps, was first used by the United States in 1916 in the Mexican Punitive Expedition.[2] During this period the Ordnance Department developed mobile artillery repair shops which allowed repairs to be made away from base shops.[3] The Mexican conflict gave both agencies experiences that would

serve them well in World War I.

In July 1917, the tables of organization and equipment for the American Expeditionary Force required 50,000 vehicles for an army of 1,000,000 men. There still was no provision for automotive maintenance. The maintenance organization was developed in France after our entry into the war.[4]

Motor transport repair facilities consisted of three classes that became the precursors of today's categories of maintenance. These classes were service, overhaul, and repair parks. Service parks were located near the front and performed light repairs. They were mobile or immobile depending on the conditions and organizations they were supporting. Overhaul parks, with more extensive facilities, did general overhaul and repairs beyond the capacity of a service park. Reconstruction parks performed major repairs and reconstruction of vehicles and components. Reconstruction parks could act as production parks undertaking emergency production and manufacture in emergencies. Salvage operations were also conducted. Facilities were permanent and locations were fixed.[5]

The Ordnance Department was responsible for weapons maintenance including towed and motorized artillery, tractors, tanks, and small arms. Mobile ordnance repair shops supported the division and army parks. Heavy artillery mobile maintenance repair shops supported the army and corps heavy artillery regiments, tank corps companies, antiaircraft units, and heavy trench mortar battalions. Heavy mobile ordnance repair shops

supported the army zone on the basis of one per four combat divisions.[6,7] The mobile ordnance repair shops evolved into the maintenance battalions we have today.

These repair shops were completely mobile. They were small, self-contained machine shops designed to repair and maintain every class of ordnance property. Heavy shops had more capability than the shops assigned to division and army parks.

This maintenance organization, like the maintenance organization for automotive equipment, also contributed to development of maintenance categories. There was a base ordnance shop (one per theater of operations) with extensive facilities. The advance base ordnance repair shop, closer to the front (one per each group of armies), provided increased capabilities and support for the corps heavy mobile ordnance repair shops in the army areas and the division mobile and heavy artillery repair shops in the forward areas.[8,9]

The army reorganized in 1920. The Motor Transport Corps, after several transfers and designations during the war, became the Motor Transport Division of the Quartermaster Corps.[10] The Ordnance Department redesignated its repair shops as light and heavy maintenance companies. Each staff department such as Ordnance and Quartermaster was responsible for the equipment it issued, as had been the case during the war. However, Ordnance also maintained automotive equipment in the artillery brigades to include equipment provided by the Quartermaster Corps. Automotive repair parts supply

remained totally a Quartermaster responsibility.[11]

The organization for maintenance that evolved from World War I was a source of procedures that would become issues for many years. For example, the current concept of supplying conventional repair parts through direct support maintenance activities has long been a controversial issue and is a deviation from supply procedures covering other classes of supply.[12] One author commented on the inefficiency of having several systems of maintenance in the combat zone.[13] This was caused by the Ordnance Department, Signal Corps, Engineer Corps and Quartermaster Corps, each having responsibility for related maintenance and supply of the commodities managed by these technical services. The technical service orientation toward materiel management was to continue until the 1960's and the implementation of the ROAD (Reorganized Army Division), COSTAR (Combat Service to the Army) and TASTA-70 (The Administrative Support, Theater Army, 1965-1970). Even the issue of consolidating motor maintenance under a single service would not be resolved until 1942.

Echelons and Categories of Maintenance

Table 1 shows a series of definitions of echelons of maintenance in the 1930's, 1942, and the present. The term "echelons" first appears in the 1930's. For example, column (1) of the table shows the five echelons of maintenance relating to automotive equipment that are contained in the 1930 Handbook for Quartermasters.[14] Ordnance also had

developed in the 1930's a loose structure of three echelons shown in column (2) of the table.[15] Basically, first echelon was what the line organization did; second echelon was what ordnance companies did and third echelon was rear maintenance.[16] In 1942, the John D. Hertz report recommended that the Motor Transport Service be given independent status as a service to assume responsibility for all motor maintenance. This issue was eventually resolved by transferring automotive materiel management responsibility to the Ordnance Department which adopted the five echelon concept shown in column (3), Table 1.[17,18] The term has been redesignated as categories with some change in definitions as shown in column (4).[19] With the exception of some expansion of organizational maintenance responsibilities, there is little real change from the early quartermaster concept.

The introduction of the echelon concept met with some criticism. Emphasis was on each level doing its job with deviations permitted only in emergencies. The concept required extensive supervision. Then, as now, commanders did not like constraints and often failed to remember the impediment to mobility caused by too many tools and repair parts. The inflexibility of the echelon concept also inhibited higher echelons from taking overflow work from lower echelons.[20] The rigidity of the concept was counter to trends in World War II for the lower echelon units to do higher level repairs in order to keep critical equipment operational.[21]

Table 1

Comparison of Maintenance Echelons

(1) QUARTERMASTER, 1930

First Echelon

Responsibility of vehicle driver. Includes cleaning, lubricating, servicing, tightening bolts and screws, performing emergency roadside repairs.

Second Echelon

Inspection, enforcement and correction of first echelon work. First and second echelon is preventive maintenance.

Third Echelon

Unit repair of assemblies, unserviceables. Unserviceables exchanged for serviceables from fourth echelon. No repairs of assemblies except minor ones requiring no disassembly. Parts must be available and authorized to be installed at this echelon.

(2) ORDNANCE, 1930's

First Echelon

Proper care of weapons and minor repairs done by the individual soldier.

Company mechanics made slightly more difficult repairs.

First echelon is preventive maintenance.

Second Echelon

Involved in more difficult repair requiring special tools and skills. Ordnance units assigned to line organizations to perform this maintenance.

(3) ECHELONS, 1942

First Echelon

Maintenance performed by the individual.

Second Echelon

Maintenance performed by the regiment, battalion and company.

Above referred to as organizational maintenance.

Third Echelon

Medium maintenance, done in mobile shops, closely supporting using troops. Overflow from lower echelons. Replacement of assemblies, e.g. recoil mechanisms, engines and transmissions. Supplied parts to using organizations.

(4) CATEGORIES, 1972

Organizational

Performed by units or activities on own materiel, crew/operator preventive maintenance services. Diagnosis and isolation of readily traceable malfunctions of modules. Replacement of modules and easily accessible parts. Evacuation of malfunctioning equipment beyond capability to repair or replace.

Direct Support (DS)

Diagnosis and isolation of equipment or module problems. Repair by replacing modules, e.g. engines, transmissions and piece parts. Establish direct exchange facility user and repair of unserviceables. Light body repairs. Provides technical assistance to user. Evacuates unserviceable materiel beyond capability to repair.

Table 1 (Continued)

Comparison of Maintenance Echelons

QUARTERMASTER, 1930	ORDNANCE, 1930's	MAINTENANCE ECHELONS, 1942	MAINTENANCE CATEGORIES, 1972
Fourth Echelon Tear down and repair of unit assemblies used in the command to which the repair facility was assigned. Multitrade shops. Semimobile.	**Third Echelon** Everything beyond capability of line and associated Ordnance organizations. Included overhaul and rebuild which went to base shops, manufacturing arsenals or Ordnance depots. Combination of characteristics of Quartermaster third, fourth and fifth echelons.	**Fourth Echelon** Heavy maintenance meaning armament work. Done in fixed and semi-fixed shops serving a geographical area. Rebuild of major items using assemblies in stock or obtained through cannibalization.	**General Support (GS)** Diagnosis and evaluation of malfunction to piece part level. Replacement of modules. Heavy body and turret repair. DS support on exception basis. Collection and classification of unserviceable major items. Operation of cannibalization point. Evacuation of disposable or unserviceables beyond capability.
Fifth Echelon Vehicle and subassembly reconstruction. Immobile shops similar to manufacturing facilities. Included procurement and development of major items.		**Fifth Echelon** Highest level. Complete reconditioning or rebuild. Limited manufacture of parts and assemblies. Third, fourth and fifth echelons referred to as service maintenance.	**Depot Maintenance** Overhaul of end items/modules. Repairs involving special facilities. Nondestructive testing to determine usability of used parts. Special inspections and modification. Manufacture of nonstocked repair parts when required. Wholesale level direct support for selected items.

The transfer of automotive maintenance responsibility and the echeloning concept also affected the army's organization for maintenance. Ordnance companies had been withdrawn from the triangular division (three regiments). Administrative and logistical overhead were to be pooled at higher headquarters. Line units were expected to serve themselves. With the exception of medical, there were no attached personnel from branches other than infantry and artillery.[22]

In 1942, the Ordnance Company was returned to the division, but General Leslie McNair, Commander, Army Ground Forces, and responsible for organization of these forces, expected the bulk of "so-called third echelon" repairs to be done by the line units to avoid losing control of their equipment in combat. The division ordnance company was therefore designed to perform about 60 percent of the third-echelon maintenance occurring under quiet conditions and only about 30 percent when the division was engaged. Overflow was to be evacuated.[23] General McNair's ideas did not take effect. Later evidence in 1945 showed that ordnance units were severely strained.[24] This was probably due to inability to train and equip line units to do the work in the short period from 1942-1945. This particular episode is significant to this study because of the alternative it presents to the current maintenance concept.

Post World War II to Present

The organization for maintenance in Korea remained essentially the same as during World War II. After Korea the

ROCID and ROCAD (Reorganization of the Current Infantry and Armored Divisions) divisions were developed. The ordnance company became the ordnance battalion. The emphasis on pooling of assets continued except that pooling occurred at division level. Organizationally, support was technical service oriented.[25]

The technical service orientation toward maintenance ended in 1962 with the reorganization of the army and the abolishment of the technical services. Maintenance was functionalized in the ROAD division.[26] The ordnance battalion was the nucleus of the ROAD maintenance battalion which provides direct support services for nearly all commodities. The functional concept was broadened to include non-divisional units with implementation of the COSTAR (Combat Service to the Army) concept in 1965 and finally to the theater of operations with TASTA-70 (The Administrative Support, Theater Army, 1965-1970) in 1968.[27,28,29]

REPRESENTATIVE STUDIES

In reviewing related literature, it was found that most studies were oriented toward improving service under the current concept of categories of maintenance. An example would be "Maintenance-75," a study completed in 1969 by the US Army Combat Developments Command Maintenance Agency, or "Maintenance Organizational Structures for Support of the Army in the Field" by the same agency. Both look at the concept of organizational and direct support maintenance as a

whole.[30,31] "Maintenance-75" describes direct support in terms of functions performed by direct support units on organizational equipment. It offers no suggestions as to changes in assignment of tasks.

Deviations from the standard structure exist and are acknowledged.[32,33] As cited in Chapter 1, aviation, engineer construction, and guided missile materiel maintenance concepts are based on the concept of organic direct support within the using organization. Generally, however, these deviations are treated as special cases. Categories and adherence thereto are considered necessary because moving responsibility for more complex tasks to forward areas adversely affects organizational mobility and is likely to result in materiel damage due to lack of training and proper tools.[34]

This doctrical reluctance has been challenged. General McNair's comments, the opposition by field commanders to limitations on their maintenance capability and combat experience indicate that the concept of maintenance categories may not be the best solution. At any rate, alternatives such as giving using organizations direct support capabilities have been successful. The American Power Jet Company study for the Deputy Chief of Staff for Logistics of aviation maintenance in Vietnam stated that attaching aviation direct support maintenance detachments directly to using organizations resulted in improved readiness and recommended the complete integration of direct support personnel into

using aviation organizations.[35] The "Army Aircraft Maintenance Structure Study" completed in 1973 by the U. S. Army Logistics Evaluation Agency proposed that amalgamation of direct and general support maintenance would result in a 50 percent reduction in overhead personnel spaces.[36] The conventional direct support level in aviation maintenance has since been integrated with the using organization in consonance with the recommendations of the above studies.

APPARENT ASSUMPTIONS AND BASIS FOR EXAMINATION

Use of innovations such as motorized artillery, tanks, trucks, airplanes and wire communication required the integration of modern technology with the conduct of war. There was no existing logistical infrastructure to support the use of these weapons. It had to be created during the war and largely in the theater of operations. Automotive equipment, for example, required an elaborate support structure to keep the equipment operational. There were, however, no National Maintenance Points, extensive component test programs, or automated supply systems. Use of the internal combustion engine was not widespread at the time. Maintenance procedures were developed by Service Departments for the equipment each developed, procured, and supported.

The Quartermaster Corps provided trucks and drivers to support front-line units. Commercial trucks were used. The service parks for these vehicles were not organic to line

units but were operated by the Motor Transport Service. Maintenance of a large fleet of vehicles is supported by a formalized maintenance echelon concept to achieve economies of scale. Division of labor among mechanics and drivers and the existence of stable, secure facilities to store and service the vehicles is not unlike operations conducted by modern firms in the transportation industry. The Ordnance Department, in being responsible for motorized artillery and later tanks, was supporting materiel unique to the military. Parts could not be procured "off-the-shelf" as was the case with trucks. An extensive supply system for military-peculiar items did not exist. Therefore, mobile machine shops were placed close to using units and fabrication was emphasized. Since maintenance had to take place in the field, both user and maintenance support people had to work at keeping the weapons operational. Thus, the early Ordnance concept of maintenance echelons concentrated on decisions as to evacuation and the ability to handle the workload as opposed to rigid definition of responsibilities.

The technical service orientation was eventually replaced with the functionalized maintenance battalion servicing nearly all commodities. However, the concept of separating maintenance responsibilities and the units to accomplish the tasks still exists with only a few exceptions. This author asserts that the lethality of the battlefield precludes reliance on exchanging equipment in combat. In peacetime, driving extended distances to support units

creates unnecessary personnel and petroleum costs. Finally, intermediate levels such as the maintenance battalion generate overhead (people, facilities, support) not directly related to the maintenance task. Therefore, to the extent possible, modular replacement of components should be made forward and detailed repair of these components should take place in areas where adequate facilities for maintenance as well as ground and air defense can be provided.

SUMMARY

This review of literature has served to describe a historical basis for examining research questions arising from the author's experience and a search for means to accomplish the maintenance mission associated with high technology war in an environment of fixed personnel ceilings. The above interpretations of the literature review should be the subject of historical research, which is beyond the scope of this study. The past experience with these issues and the drive to reduce support costs should, however, encourage new looks at maintenance policies.

CHAPTER 2

FOOTNOTES

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CHAPTER 3

METHODOLOGY

OVERVIEW

This chapter discusses the methodology used to compare the current maintenance concept and the proposed maintenance concept. Analytical methods and computer simulation will be used. Tool costs, training, and variable costs associated with direct support maintenance of the M151 series of trucks will be examined.

RESEARCH METHODOLOGY

As previously stated, the basis for moving maintenance responsibility forward should be developed from analysis of specific materiel systems rather than commodities in the hands of combat units. This study will develop a methodology to apply to various items of materiel. The methodology will be applied to the ¼-ton truck, M151A1, which is simple enough to provide a starting point. Given the development of a sound methodology, the analysis may be applied to more complex items such as heavier trucks, armored personnel carriers and tanks.

Maintenance responsibilities are assigned through the Maintenance Allocation Chart (MAC). The MAC for the ¼-ton

truck is contained in technical manual (TM) 9-2320-218-20, the organizational maintenance manual for the vehicle. Components replaced by direct support maintenance units are the engine, oil pump, clutch, transmission/transfer assembly (replaced as a unit), and steering gear assembly.[1] Therefore, this study will examine tool and skill requirements to replace the above items and simulate scenarios where these items are replaced under the current and proposed concepts of maintenance.

Data Base

The data used is taken from the Sample Data Collection Plan Analysis Report for the M151 series of trucks developed under the provisions of Army Regulation 750-37, Sample Data Collection - The Army Maintenance System (TAMMS). The report includes data recorded from the operation of 208 vehicles during a two-year period for a total of 5,224,908 miles. During this period there were 6,995 Maintenance actions of which 408 received support maintenance. Direct Support maintenance requirements for the above-mentioned components were as follows:

Component	Failures
Engine	79
Transmission/transfer assembly	125
Clutch assembly	134[2]
Steering gear assembly	2[3]
Oil pump	0[4]

Based on the above, the oil pump will not be discussed in the study since no failure occurred in the sample.

Training Costs

Training costs are dependent upon the length of training courses and the facilities required to conduct the courses. One of the arguments for providing varying degrees of competence to mechanics based on the tasks to be performed has been that the short retention time of soldiers makes extended training very costly in terms of return received. Therefore, two automotive military occupational specialties (MOS) will be examined for content relating to the components shown above to determine the additional skills necessary to permit organizational mechanics to replace components on the M151 series of trucks that are now replaced by direct support units.

Specialties to be evaluated are:

MOS 63H20, Automotive Repairman. Performs direct and general support maintenance on wheel and track vehicles and materials handling equipment less propulsion motors on electric materials handling equipment. Diagnoses malfunctions and isolates causes. Tests, repairs, overhauls, adjusts, and replaces assemblies, subassemblies, and components such as engines (gasoline, diesel, and multifuel), clutches, transmissions, differentials, steering assemblies, transfer cases and hydraulic cylinders and components by replacing valves, shafts, gears, bearings, rings and seals, using jacks, pullers, gages, and rigs.[5]

MOS 63C20, Track Vehicle Mechanic. Performs organizational maintenance on wheel and track vehicles in

operational units and direct and general support activities.[6]

The training programs will be compared by listing subjects and hours contained in the program of instruction (POI) for MOS 63C20, Track Vehicle Mechanic, and comparing the POI to that of the POI for MOS 63H20, Automotive Repairman. The first listing will display the entire program of instruction for MOS 63C20 to provide an idea of the total training the organizational mechanic receives. The next listing will display the subjects in the program of instruction for MOS 63H20 that related to wheeled vehicles in general. Subjects relating to the M151 series of trucks will be shown by an asterisk to indicate the minimum training an organizational mechanic, MOS 63C20, would have to receive to enable him to replace ¼-ton truck engines, transmissions, clutches, and steering gear assemblies.

Programs of instruction to be used are:

POI for 610-63H20	Automotive Repair Course MOS 63H20, January 1973, U. S. Army Ordnance Center and School
POI for 611-63C20	Track Vehicle Mechanic Course MOS 63C20, December 1974, U. S. Army Armor School.

Tool Costs

Tool costs that would be incurred if responsibility for replacing the above components was moved forward will be evaluated by examining replacement procedures contained in TM 9-2320-218-34, Direct and General Support Maintenance

Manual. Direct support maintenance units, both divisional[7] and non-divisional[8] use the same tool sets to perform automotive maintenance. The sets are Shop Equipment Automotive Maintenance and Repair: Field Maintenance Basic and Field Maintenance Supplemental No. 1. Special tools required for specific vehicles are shown in the Direct and General Support Maintenance Manual.[9] Tools required for replacement of the above components that are not contained in organizational tool sets would have to be added. The price of these tools will be obtained from the Army Master Data File, December, 1974. Data will be displayed as follows:

SPECIAL TOOL REQUIREMENTS

Replacement Task	Tool Nomenclature	FSN	Cost	Reference
Engine				
Transmission/ Transfer				
Clutch				
Steering Gear Assembly				

COMPARISON OF VARIABLE COSTS

Discussion

One objective of this study is to compare variable costs generated under two different concepts of providing direct support maintenance services for the M151A1 ¼-ton truck. Consistent with the current description of the direct support category of maintenance, replacement of the engine, transmission, clutch and steering gear assembly is performed by a direct support unit. The alternative concept proposed in this study would have replacement of these components become organizational maintenance responsibilities and redefined in the Maintenance Allocation Chart for the M151 series of trucks.

Variable costs will be collected for maintenance actions performed under each policy. A computer simulation will be used to generate maintenance actions and compare costs. The purpose of developing a system model is to determine the performance of the system without having to actually assemble that system. Constructing the model of a logistic system is difficult because of inherent complexity.[10] Therefore, the goal of a model should not be to attempt to portray all the variables or attempt complete duplication of reality, but to "abstract the essence of problems."[11] Thus, certain factors must be omitted and assumptions must be made to achieve the objective of the simulation within constraints such as programing capability and time.

Department of the Army Pamphlet 750-21, Logistics

Support Modeling, lists the following questions that simulation may answer.[12]

1. When will units fail?
2. How long will it take to fix it?
3. When will replacement parts arrive?
4. How many man-hours are necessary?
5. What is the cost per man-hour?
6. What skills are necessary to repair the units?

Component Failure. Unscheduled maintenance requirements of all kinds occur in the simulation based on an inherent reliability of .98 for the M151A1 derived from the Sample Data Collection effort.[13] During the period of data collection, there were 6,995 unscheduled requirements of which 408 were for direct support maintenance services giving a probability of .0583 that an unscheduled maintenance requirement requires direct support services.[14] The selection of the component that fails is based on the following probabilities.

P(Component) = number of component failures/number of direct support requirements
P(Engine) = 79/408 = .1936
P(Trans/Tnsfr) = 125/408 = .3064
P(Clutch) = 134/408 = .3284
P(Steering Gear) = 2/408 = .0049
P(Other DS Task) = 68/408 = .1667[15]

Repair Time. Man-hours directly related to repair of the above components are developed using exponentially distributed random variables. Mean service times used to

compute the mean of the exponential distribution are taken from the Sample Data Collection Plan Analysis Report for the M151A1 series of trucks. Component replacement times are discussed in greater detail later in this chapter.

<u>Repair Parts Availability</u>. In this study it is assumed that repair parts are on hand whether the maintenance is accomplished at the support unit or at the organization. It can be argued that the organization would not be likely to carry spare components due to their low demand, cost, and size. However, routine supply runs to division or brigade logistic areas must occur daily. Turn in and issue could be accomplished in this manner. It is also highly probable under current concepts that the direct support unit would be out of stock. Time limitations did not permit development of routines to simulate resupply operations.

<u>Man-hour Requirements</u>. In evaluating the current concept, man-hours, generated using the models already shown, are totaled based on the sum of the time to prepare the vehicle for receipt by the direct support unit, the transportation time to deliver and pick up the vehicle in terms of the people involved, and the direct man-hours required to replace the faulty component.

<u>Labor Costs</u>. The cost per man-hour used is $6.48 based on the Sample Data Collection Plan Analysis Report.[16]

<u>Skill Requirements</u>. It is assumed that individuals

performing the task have the requisite skills. No assumptions are made as to the number of individuals performing the maintenance task, since man-hour figures are used. Numbers of people are relevant to transportation time computations.

Additional Costs. Costs of fuel and lubricants are computed in connection with transportation to direct support units. Computations are discussed in detail later in the chapter.

General

This portion of the study develops models for each of the concepts that will portray man-hours necessary to perform the corrective actions in question. These man-hours are multiplied by hourly wage figures to obtain labor costs. Additionally, costs of petroleum, oil, and lubricants to transport disabled vehicles are computed. Monthly costs are summed for each concept, monthly cost differences are computed, and a statistical test is used to test the statistical significance of the cost differences, i.e., that there is a statistical basis for stating that the concepts result in different costs.

Current Concept

The model used for evaluating the current concept proposes that there are three elements contributing to time required to perform a given direct support maintenance task. These are the time required to perform the direct support maintenance task (DSMNTM), the time required to transport the

vehicle to the direct support unit (TRANSTM) and the time required to prepare the vehicle for acceptance by the DSU (OGPRPTM) by assuring that all organizational maintenance has been performed before action is taken by the direct support unit to correct a problem. This concept will be designated Concept A. The maintenance time generated under the Concept A model will be represented by the symbol AMNTTIM. Symbolically displayed: AMNTTIM = OGPRPTM + TRANSTM + DSMNTM.

Proposed Concept

Under the proposed concept (Concept B) that major component replacement be performed at battalion organizational maintenance level, organizational preparation time and transportation time are dropped from the equation. The time required to correct organizational deficiencies becomes a part of routine maintenance work as does technical inspection to verify that organizational maintenance has been performed. Transportation time is not necessary since the work is performed in the battalion.* Therefore, for Concept B, the equation is: BMNTTIM = DSMNTM.

Labor Costs

Labor costs for time accumulated under each concept are the product of the time and the hourly labor rate of $6.48.

---

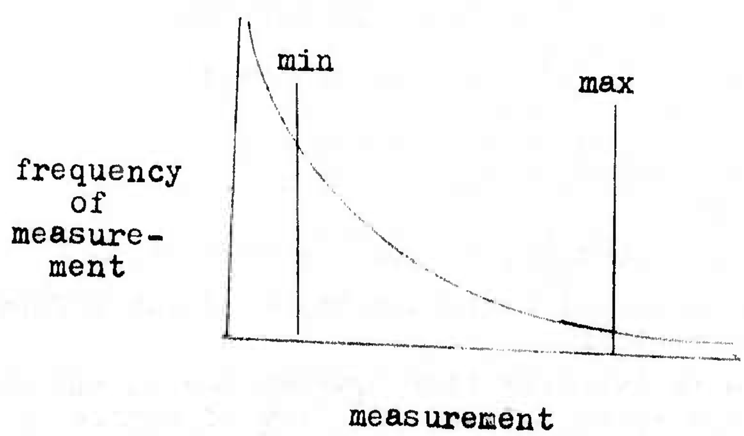
*It is acknowledged that some transport is required to obtain the major components since items such as engines would not be stocked in the using units in order to avoid costs of proliferating such items. However, components may be placed on transportation engaged in resupply of several classes of items.

AMNTCST = AMNTTIM * 6.48
BMNTCST = BMNTTIM * 6.48

Elements of Maintenance Time

Direct support maintenance time (DSMNTM) and organizational preparation time (OGPRPTM). Times to replace the engine, transmission, clutch, steering gear assembly, the accomplishment of all other direct support maintenance requirements and organizational preparation time are generated through use of mean replacement times obtained from the Sample Data Collection Plan Analysis and exponential distribution functions based on those mean values. Arbitrary minimum and maximum values determined by the author are also placed in these functions to avoid unrealistically low or high time values.

The exponential distribution is often used to represent service times.[17] The shape of the distribution is shown below. The vertical lines designated "min" and "max" represent the constraints introduced to limit maintenance times.



Exponentially distributed service times to replace components are generated using a FORTRAN computer language function based on the equation

$$x_s = -\frac{\ln y_s}{xmu}$$

where

x_s = exponentially distributed service time

$xmu = \frac{1}{\text{mean service time}}$ = distribution mean

y_s = a uniformly distributed random number.

Thus, the natural logarithm of a uniformly distributed random number divided by the mean of the exponential distribution provides the random service time. The above equation is used to generate service times for the engine, transmission, clutch, steering gear assembly, other direct support tasks, and organizational preparation time previously mentioned. An example FORTRAN function used in the simulation to generate engine replacement times is shown below.[18] Conditional ("IF") statements prevent the time to replace from being less than 7 or more than 19 man-hours.

```
      FUNCTION ENGINE (DUMMY)
C ENGINE REPLACEMENT TIME. DEFINES MIN AND MAX
     TIMES. EXPONENTIAL DISTRIBUTION.
      XMU = 1./9.5
      EXPTIM = (-1./XMU)*ALOG(RANF(A))
      ENGINE = EXPTIM
      IF (ENGINE.LT.7.) ENGINE = 7.
      IF (ENGINE.GT.9.) ENGINE = 19.
      END
```

XMU = mean of distribution, 1/ mean service time

EXPTIM = exponentially distributed value of the engine replacement time

ENGINE = engine replacement time transmitted to the main program and which varies each time an engine is repaired

Similar functions are used to generate time values for the transmission, clutch and steering gear assembly replacements, all other direct support maintenance requirements, and organizational preparation time. Table 2 lists input parameters.

Table 2

Function/ Component Federal Stock Number	Mean Service Time (MST)	Mean of Exponential Distribution (XMU=1/MST)	Min/Max Values	Sample Data Collection Report Reference For MST
ENGINE 2805-886-8083	9.5	.105	7./19.	p. 125
TRANSMISSION 2520-678-1808	6.7	.149	5.5/13.4	p. 139
CLUTCH 2520-887-1353	4.2	.238	3.5/8.4	p.1122
STEERING GEAR 2530-769-7263	5.5	.182	4.75/11.	p. 126
OTHER	10.0	.100	1./30.	p. 7
OGPRPTM	8.0	.125	0./30.	Author Estimate

<u>Transportation Time (TRANSTM)</u>. Transportation time to effect corrective action depends on the distance to the direct support unit and the average speed of the vehicle. The process generator for this variable must provide for the time (man-hours) to take the vehicle to the direct support unit, drop off the vehicle and return to the parent unit. This factor is represented by the variable TOTIME. The process generator must also provide for returning to the direct support unit, picking up the vehicle and returning to

the parent unit. This variable is represented by the symbol FRMTIME. Since the trip to the direct support unit is likely to involve a wrecker which generally requires an assistant driver and the trip to pick up the vehicle will require at least another ¼-ton truck as a taxi vehicle it is assumed that two men are involved on each of the trips.

The process generator is constructed to permit variable times transporting the vehicle to and from the direct support unit. The following equations apply.

$$\text{Time} = \frac{\text{Distance to DSU (Support Miles)}}{\text{Rate}} = \frac{\text{SPTMIS}}{\text{25 mph}}$$

Assume that the fastest a driver could go one way is $.75 * \frac{\text{SPTMIS}}{25}$. Assume also that the time could be greater than the fastest possible time by a variable factor up to $1. * \frac{\text{SPTMIS}}{25}$.

Based on these assumptions and the use of the uniformly distributed random number generator to provide a factor from 0 to 1 to vary transportation time, the following model to develop transportation times for disabled vehicles is used.

```
TOTIM1  = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
TOTIM2  = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
FRMTIM1 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
FRMTIM2 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
TRANSTM = 2.*(TOTIM1 + TOTIM2 + FRMTIM1 + FRMTIM2)
```

TOTIM1 and TOTIM2 are trips to and from the direct support unit towing the disabled vehicle. FRMTIM1 and FRMTIM2 are trips to and from the direct support unit to pick up and return the repaired vehicle. TRANSTM is the total

man-hours involved in delivery and return of the vehicle where the factor "2" is the number of drivers and assistant drivers involved.

Fuel and Oil (POL) Costs

Fuel and lubricant costs are computed based on two sets of factors. The first set is from FM 101-10-1, Staff Officer's Field Manual; Organizational, Technical, and Logistical Data; Unclassified Data dated 26 July 1971. The second set is from the Research Analysis Corporation (RAC) study, "Fuel and Oil Costs for Army Equipment," published in 1968. The RAC study states that actual consumption calls for much higher factors to be used than are called for by the 1966 FM 101-10-1.[19] The RAC statement still applies. It is noted that the Army factor for the ¼-ton truck (.03 gallons per kilometer which is approximately .05 gallons per mile) implies that the ¼-ton truck achieves 20 miles per gallon of gasoline.[20] The RAC measured factor of .094 gallons per mile taken from observations of trucks operated at Fort Carson, Colorado, implies that the ¼-ton truck achieves 11.1 miles per gallon. The simulation is conducted using both sets of factors.

Fuel and lubricant (POL) prices were obtained from the Installation Supply and Services Division, US Army Combined Arms Center at Ft. Leavenworth and represent latest contract prices.

The simulation assumes that a disabled vehicle would be towed to the direct support unit by a 5-ton wrecker.

Therefore POL costs per mile for the 5-ton wrecker (POLCPM1) must be computed and used to collect costs for the trip to and from the DSU. On pickup of the repaired vehicle it is assumed that one ¼-ton truck with a driver and a driver for the repaired vehicle goes to the DSU. Both vehicles make the return trip home. POL cost per mile for the ¼-ton truck must be computed and used to collect costs associated with returning the repaired vehicle to the owning unit.

The process generator for the cost of the trip to the DSU (TOCOST) is:

TOCOST = SPTMIS*POLCPM1*2.

where SPTMIS is the distance between the owning unit and the DSU. The factor "2" accounts for the trips to and from the DSU with a wrecker to deliver the disabled vehicle.

The process generator for the cost of trips to pick up the repaired vehicle (FRMCOST) is:

FRMCOST = 3.*SPTMIS*POLCPM2

where the factor "3" is the number of ¼-ton truck trips involved in return of the repaired vehicle.

The total cost of POL (POLCST) for each direct support maintenance requirement is:

POLCST = TOCOST + FRMCOST.

The model for computing POL costs per mile is as follows:

$$\begin{array}{c}\text{POLCPM1} \\ \text{or} \\ \text{POLCPM2}\end{array} = \frac{\text{gal (gas)}}{\text{mile}} * \frac{\text{price (\$)}}{\text{gal}} + \frac{\text{gal (oil)}}{\text{mile}} * \frac{\text{price (\$)}}{\text{gal}} +$$

$$\frac{\text{lbs (gear lube)}}{\text{mile}} * \frac{\text{price (\$)}}{\text{lb}} + \frac{\text{lbs (grease)}}{\text{mile}} *$$

$\frac{\text{price (\$)}}{\text{lb}}$.

The following tables show unit prices of various POL products and the units per mile factors for the 5-ton wrecker and the ¼-ton truck.

Table 3

POL Prices[22]

Product	FSN	$/Unit (gallons or pounds
MOGAS	9130-264-6218	$ .36 per gallon
Oil (OE30)	9150-189-6729	$ .78 per gallon
Oil (GO 90-gear oil)	9150-577-5844	$1.09 per pound
Grease GAA	9150-190-0907	$1.42 per pound

Table 4

POL Usage Factors and Costs Per Mile[23,24]

Item	Factors				
Wrecker	MOGAS gal/mi	OIL OE-30) gal/mi	OIL OE-90) lbs/mi	Grease (GAA) lbs/mi	POL Cost Per Mile $/mi
FM 101-10-1	.367	.008	.005	.008	.15
RAC Study*	.909	.038	.005	.008	.376
¼-Ton M151A1					
FM 101-10-1	.05	.002	.002	.002	.03
RAC Study*	.094	.003	.002	.002	.041

*The RAC Study has no factors for Oil (OE-90) and Grease (GAA). Therefore the FM 101-10-1 factors were used.

Costs for POL under the current concept, Concept A, are collected for each vehicle. Costs for POL under Concept B are assumed to be zero, since maintenance is performed in

the battalion area. As previously noted (footnote page 34), there would be transportation costs incurred in the delivery of components. It is assumed here that components could be delivered as part of regular resupply which would include several classes of items.

Additional Comments

Organizational Maintenance Time (OGMNTM). This is the time required to perform tasks currently shown in the Maintenance Allocation Chart as the responsibility of the using organization. Although not directly germane to the study, the capability to generate and record organizational maintenance time has been incorporated into the simulation.

The Sample Data Collection Plan Analysis Report assumed the normal distribution in connection with organizational maintenance statistics.[25] To generate normally distributed organizational maintenance times the method developed by G. E. P. Box and M. E. Muller is used.[26]

$$X = (-2.* \ln U1)^{\frac{1}{2}} \cos(2*\pi*U2)$$

where

X = a normally distributed random variable
$U1$ and $U2$ = uniformly distributed random numbers.

The Computer Program. Variables used in the computer program are defined in Appendix A. The computer program flow chart with detailed explanation is in Appendix B. A listing of the computer program is in Appendix C.

HYPOTHESIS TESTING

The hypothesis to be tested is that shifting major

component replacement responsibility for the M151A1 ¼-ton truck from direct support unit to the organizational maintenance level will result in a decrease in total variable maintenance costs.

Statistical Testing

The structure of the models for the current direct support maintenance concept and the proposed concept is such that the current concept will always lead to higher total maintenance costs than the proposed concept. The difference between mean monthly costs generated under the two concepts will be tested for statistical significance. The Student's "t" test will be used.

One of the necessary assumptions in using the Student's "t" test is that the random sample is taken from a normal distribution. With small samples, however, such as twelve month simulation periods, this cannot be assumed. On the other hand empirical studies of the "t" distribution indicate that moderate departures from normality do not greatly affect the probability distribution of the statistic. Therefore, the distribution will be used for hypothesis testing in this study.[27]

Computation of the Sample Test Statistic (T). Monthly costs for each vehicle are totaled for each concept. The cost totals under Concept B are subtracted from costs incurred under Concept A. The cost differences are summed and divided by the number of trucks in the organization to give the mean

cost difference between the concepts per truck for a given month. Mathematically, the equation is

$$\bar{D} = \frac{\Sigma X_A - \Sigma X_B}{N}$$

where

$\bar{D}$ = mean difference per truck for a month (DBAR)

ΣX_A = total maintenance costs for a truck for the month under the current concept (ATOTCST)

ΣX_B = total maintenance costs for a truck for a month under the proposed concept (BTOTCST)

N = number of trucks (XTRUCKS)

The monthly mean cost differences per truck are summed for the period and divided by the number of months in the simulation run to give the mean of the monthly mean cost differences. This figure is also called the grand mean.

$$\Sigma\bar{\bar{D}} = \sum_{J=1}^{M} \bar{D}_J$$

where

$\bar{\bar{D}}$ = grand mean (GRDDBAR)

M = number of months in the simulation (XMONTHS)

J = variable from 1 to M.

<u>Null Hypothesis</u>. The null hypothesis is that there is not a significant difference in monthly maintenance costs per truck generated by the two concepts. The expected value of the mean of the difference in monthly mean costs per truck would be zero. Thus,

$$H_O: E(\bar{\bar{D}}) = O.$$

where

$\bar{\bar{D}}$ = mean of the monthly mean differences in total maintenance costs per truck for the two concepts (grand mean).

Alternative Hypothesis. The alternative hypothesis is that there is a significant difference in monthly maintenance costs per truck generated by the two concepts.

$$H_A: E(\bar{\bar{D}}) > 0.$$

The standard deviation of the grand mean ($\bar{\bar{D}}$) is computed. The statistic measures the dispersion of the sampling distribution and is called the standard error of the mean.[28] The equation is:

$$\hat{S}_{\bar{\bar{D}}} = \frac{\hat{S}_{\bar{D}}}{\sqrt{M}}$$

where

$\hat{S}_{\bar{\bar{D}}}$ = standard error of the grand mean

$\hat{S}_{\bar{D}}$ = standard error of the monthly mean cost differences per truck.

The equation for $\hat{S}_{\bar{D}}$ is:

$$\hat{S}_{\bar{D}} = \sqrt{\frac{\sum_{J=1}^{M} (\bar{D}_J - \bar{\bar{D}})^2}{M-1}}$$

where

$\sum_{J=1}^{M} (\bar{D}_J - \bar{\bar{D}})^2$ = summed squares of deviations between the monthly mean cost differences per truck and the mean of the monthly mean cost differences

$M-1$ = number of months in simulation less one, which is the number of degrees of freedom.

The computed test statistic is developed from the equation:

$$T = \frac{\bar{\bar{D}} - E(\bar{\bar{D}})}{\hat{S}_{\bar{D}}/\sqrt{M}}$$

Since $E(\bar{\bar{D}}) = 0$

$$T = \frac{\bar{\bar{D}}}{S_{\bar{D}}/\sqrt{M}}$$

where

$\hat{S}_{\bar{D}}$ = sample standard deviation.

M = months in the simulated period.[29]

Rejection Region. The confidence level of the test will be .95. The probability of rejecting the null hypothesis when it is true will be .05. The test statistic is selected based on this confidence level and the number of degrees of freedom (M-1) determined by the sample size. For a simulation of twelve months the number of degrees of freedom is 11. The appropriate test statistic is $t_{.05} = 1.812$.[30]

If the computed "T" value from the simulation is greater than 1.812, the mean difference in costs generated by the two concepts is sufficiently large to conclude that the proposed concept results in a statistically significant decrease in maintenance costs.[31]

Experimental Design

Collection of costs and the statistical test for significance of the differences in costs generated by the models of the current and proposed concepts will be made by simulating the occurrence of direct support maintenance requirements on a fleet of ¼-ton trucks. The base unit will be a mechanized infantry battalion which has 28 organic ¼-ton trucks.[32]

Various distances from the battalion to the direct support unit will be used. A distance of 1 mile simulates co-location of the battalion with a divisional forward support

maintenance company. Distances of 10, 25, 50, and 100 miles simulates separation from the direct support unit which could occur on training exercises or fast moving offensive operations. It is not uncommon for non-divisional units to be separated by such distances from direct support units during normal operations in overseas commands. It is further recognized that divisional maintenance units would attach "contact" teams to provide on-site support. Use of contact teams, however, is actually a means of implementing the alternative concept proposed in this study with the exception that for personnel management purposes, the team members would still be assigned to the direct support unit.

The simulation will be performed using the Sample Data Collection Plan Analysis Report inherent reliability of .98. An additional simulation with a reduced inherent reliability of .90 will also be made to evaluate the effect of an increased number of breakdowns that could occur during field exercises or combat operations.

Finally, the fuel and oil costs will be varied according to the Research Analysis Corporation Study and FM 101-10-1 to obtain an indication of the effect of petroleum, oil, and lubricant costs on the cost differences generated by the two concepts.

All simulations will include a series of runs in which organizational preparation time is zero to assess the effect of transportation costs alone. Figure 1 shows how data will be displayed for each simulation.

Figure 1

Table Format

Simulation No
Inherent Reliability
Number of Trucks
Number of Periods
POL Cost per Mile - Wrecker
POL Cost per Mile - M151A1
Test Statistic $t_{.05/11df}$

(1) Run No	(2) SPTMIS	(3) GRDDBAR	(4) S	(5) T	(6) Accept/Reject H_o	(7) DSBKDNS	(8) OGPRPTM

Key

(1) Self-explanatory
(2) Distance to direct support unit
(3) Mean of monthly mean cost differences (grand mean)
(4) Standard error of the grand mean
(5) Computed test statistic
(6) Statement of acceptance or rejection of the null hypothesis
(7) Number of direct support maintenance requirements for all trucks
(8) Indication that organizational preparation time is used

Chapter 3

FOOTNOTES

1. U. S. Department of the Army, TM 9-2320-218-20 with change 3, Organizational Maintenance Manual, Truck Utility: ¼-ton, 4x4, M151, M151A1, M151A2 (Washington: The Adjutant General, 23 September 1971), p. B-2.

2. U. S. Army Tank-Automotive Command, Sample Data Collection Plan Analysis Report: Truck, Utility, M151A1/A2, ¼-ton (U. S. Army Maintenance Management Center: 30 May 1974), p. 27.

3. Sample Data Collection Plan Analysis Report, p. 126.

4. Sample Data Collection Plan Analysis Report, pp. 131-133.

5. U. S. Army Department of the Army, Army Regulation 611-201 with changes 1 through 3, Enlisted Career Management Fields and Military Occupational Specialties (Washington: The Adjutant General, 1 October 1937), p. 3-63-39.

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7. U. S. Department of the Army, Table of Organization and Equipment (TOE) 29-25H, Maintenance Battalion, Infantry Division (mechanized) (Washington: The Adjutant General, 30 November 1970), p. 12.

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10. Department of the Army Pamphlet (DA Pam) 750-21, Logistic Support Modeling (Washington: Government Printing Office, 3 September 1970), p. 2-1.

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14. Sample Data Collection Plan Analysis Report, p. 21.

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19. J. O'Flaherty and R. J. O'Rorke, Jr., Fuel and Oil Costs for Army Equipment (McLean, Virginia: Research Analysis Corporation, November 1968), p. 17.

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21. J. O'Flaherty and R. J. O'Rorke, Jr., p. 29.

22. Fuel and oil prices obtained telephonically from Installation Supply and Services Division, U. S. Army Combined Arms Center and Fort Leavenworth, 1 May 1975.

23. FM 101-10-1, p. 5-8.

24. J. O'Flaherty and R. J. O'Rorke, Jr., p. 29.

25. Sample Data Collection Plan Analysis Report, p. 58.

26. G. E. P. Box and M. E. Muller, "A Note on the Generation of Random Normal Deviates," Annals of Mathematical Statistics, XXIX (1958), pp. 610-11, cited by A. Alan B. Pritsker and Philip J. Kiviat, Simulation with Gasp II, A FORTRAN Based Simulation Language (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969), p. 97.

27. William Mendenhall and Richard L. Scheaffer, _Mathematical Statistics with Applications_ (North Scituate, Massachusetts: Duxberry Press, 1973), p. 345.

28. Lincoln L. Chao, _Statistics: Methods and Analyses_ (New York: McGraw-Hill Book Company, 1969), p. 136.

29. Chao, pp. 262-265.

30. Mendenhall and Scheaffer, p. A31.

31. Mendenhall and Scheaffer, p. 344.

32. U. S. Department of the Army, TOE 07-045H SRC 07045H030, Infantry Battalion (Mechanized), equipped with TOW (U. S. Army Combined Arms Center, 10 April 1975), p. III-15.

CHAPTER 4

FINDINGS (ANALYSIS AND EVALUATION)

RESEARCH QUESTIONS

DATA AND FINDINGS

Research Question 1

What are tool and equipment costs incurred by moving responsibility for replacement of engines, transmission/transfer assemblies, clutches, and steering assemblies forward to the using organization for the M151A1 ¼-ton truck?

Table 5 lists tools required to perform the task, cost, and whether required at organizational level or already on hand.

Research Question 2

What are the costs associated with providing additional skills at the organizational level to permit replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies?

Table 6 shows the current program of instruction (POI) for MOS 63C20, Track Vehicle Mechanic. The emphasis in the POI is on performance of organizational maintenance tasks as described in the "-20" series of technical manuals for tracked and wheeled automotive equipment. A small number of hours is devoted to maintenance management (e.g. maintenance records, use of publications).[1]

Table 7 is a list of courses drawn from the program

of instruction for MOS 63H20, Automotive Vehicle Repairman that relate to wheeled vehicles and, in particular, the M151A1 ¼-ton truck.

Findings for Research Question 1

Based on analysis of tools required to perform replacement of engine, transmission/transfer, clutch, and steering gear assemblies, only the engine lift sling is required since 5-ton wreckers organic to using battalions can lift the assemblies. This sling was apparently produced for a one-time issue to support units. It is no longer carried in the Army Master Data File except to indicate that it is no longer stocked.[2] Estimated cost to manufacture is $150.00.

If it is desired to issue the hoist currently issued to automotive direct support units, the Army Master Data File price is $156.00.[3] The spanner wrench for engine removal is used to remove the generator cable and is on hand. The inch-pound torque wrench and the spring scale necessary to replace the steering gear assembly are already contained in the Organizational Maintenance Number 2 Common tool set.

Therefore, it is estimated that the cost of equipping a battalion to replace components now serviced by direct support units would be approximately $150 to $300.

Table 5

M151A1 Tool Requirements
Major Component Replacement

Task	Tool	FSN	Cost*	
Engine, Transmission/ Transfer Removal	SLING, Engine and Transmission (7345279)	3940-692-9112	Estimated $150.00	TM 9-2320-218-34, pp. 4-16
	HOISTING UNIT, Automotive Maintenance	4910-448-0254	$156.00	SC 4910-95-CL-A3, p. 12
Clutch	No special tools cited			TM 9-2320-218-34, pp. 15-3 to 15-5
Steering Assembly Replacement	WRENCH, TORQUE; 200 in-lb	5120-853-4538	Currently in organizational maintenance tool set	TM 9-2320-218-34, p. 16-1. SC 4910-95-CL-A74, p. 13 SC 4910-95-CL-A72, p. 19
	SCALE, PULL Dial Indicating	6670-254-4634	Currently in organizational tool set	TM 9-2320-218-34, pp. 16-7, 8 SC 4910-95-CL-A72, p. 13

*Costs obtained from Army Master Data File, December 1974.

Table 6

Extract
Program of Instruction
Track Vehicle Mechanic
MOS 63C20

Annex Title and Subjects	Hours
Maintenance Management	
Maintenance Publications 30202	2
The Army Maintenance Management System 30305	5
Repair Parts Supply	2
Annex Total	9
Engines	
Carbureted Gas Engine	
Track Vehicle Mechanic	1
Engines	4
Cylinder Head Replacement	3
Automotive Electricity	4
Low Voltage Circuit Tester and Multimeter	6
Wiring Diagrams	2
Storage Batteries	2
Cooling and Lubricating Systems	1
Cranking System	2
Battery Ignition System	8
Carbureted Fuel System	7
AC Charging System	4
DC Charging System	4
Performance Examination, Carbureted Gas Engine	5
Subannex Total	53
Gas Injected Engine	
Cooling and Lubricating Systems	3
Hull Electrical Systems	5
Cranking System	3
Magneto Ignition System	12
Intake and Exhaust Systems	3
Gasoline Injected Fuel System	10
DC Charging System	2
Hull Mechanical Components	4
Performance Examination, Gas Injected Engine	8
Subannex Total	50

Table 6 (continued)

Annex Title and Subjects	Hours
Compression Ignition Engine	
Cooling and Lubricating Systems	3
Hull Electrical Systems	4
Cranking Systems	4
Intake and Exhaust Systems	3
Compression Ignition Fuel System, 2-Stroke-Cycle	10
Compression Ignition Fuel System, 4-Stroke-Cycle	11
AC Charging Systems	5
DC Charging System	3
Performance Examination, Compression Ignition Engines	8
Subannex Total	51
Annex Total	154
Periodic Services	
Wheel Vehicle	
Clutches and Transmissions	8
Transfer Assembly	5
Suspension Systems	3
Axles	6
Steering Systems	5
Brake Systems	8
Wheels and Tires	3
Semiannual PM Services	7
Performance Examination, Wheel Vehicle Maintenance	7
Subannex Total	52
Chassis and Associated Materiel	
Closed Breech Scavenger System	2
Transmissions	12
Controlled Differential	3
Geared Steer Unit	4
Performance Examination, Power Trains	5
Tracks, Road Wheels, and Torsion Bars	9
Shock Absorbers	4
Final Drives	4
Personnel Heaters	4
Performance Examination, Suspension System	5
Subannex Total	52

Table 6 (continued)

Annex Title and Subjects	Hours
Armored Personnel Carrier	
Transmission and Transfer	12
Controlled Differential and Final Drive	5
Hull Mechanical Components	3
Hydraulic Ramp	4
Quarterly PM Services and Proficiency Examination	20
Shop Safety	1
Tools	2
Subannex Total	47
Tank	
Quarterly PM Services and Proficiency Examination	44
Subannex Total	44
Annex Total	195
Ground Mobility	
Recovery Vehicles	
Hydraulic Principles	1
Hydraulic Spade	4
Suspension Lockout	4
Hydraulic Boom Components	6
Hydraulic Winch and Hoist	12
Performance Examination, Hydraulic Systems	6
Subannex Total	33
Vehicle Operations	
Wheel Vehicle Driving	8
Track Vehicle Driving	5
Subannex Total	13
Annex Total	46

Table 7

Extract
Program of Instruction
Automotive Repairman
MOS 63H20

Course Title and Scope	Hours
Engines	
Introduction to Military Vehicle Components Purpose, model number and identification of wheel vehicle power train and chassis components. Practical exercise on identifying wheel vehicle power train components. p. A-3	1
Issue, Care, and Use of Handtools Components of general mechanic's handtool set. Practical exercise on performing measurements using a dial indicator, torque wrench and spring tension gage. p. A-5	2
Engine Construction Purpose of components and valve and cylinder arrangements of military engines. Paper practical exercise on identification of engine components. p. B-1	4
Engine Principles Principles of operation of spark ignition and compression ignition of stroke cycle engines. p. B-1	1
Engine Disassembly Disassembly of engine. Removal of one valve and one piston with rod assembly to include practical exercise. p. B-1	4
Engine Cooling System Coolent, additives, identification of components. p. B-1	1
Engine Lubricating System Oils function, identification of components and operation of engine lubricating systems. p. B-2	1
Micrometers, p. B-2	2
Valve and Valve Seat Reconditioning, p. B-2	4
Engine Inspection and Measurements, p. B-3	3
Engine Assembly, p. B-3	5
Fuel Systems Systems, pumps, carburetors. pp. B-3, B-4	9

Table 7 (continued)

Course Title and Scope	Hours
Electrical Systems Basic electricity and magnetism. Low voltage circuit tester. Batteries. Starting system. Instruments and gages. Wheel vehicle charging systems. pp. B-5 through B-8	28
Troubleshooting Wheel vehicle engine malfunctions, p. B-8	2*
Wheel Vehicle Engine Tune-up, p. B-9	5
Transfer Assembly Construction, power flow, and adjustment of a transfer and parking brake. A practical exercise on disassembling, inspecting, assembling, and adjusting a transfer assembly and parking brake. p. D-1	6
Steering Systems Types, construction, operation, and adjustments of conventional steering gears	2*
Dry Disc Clutch Types, construction, and operation of the dry disc clutch. p. C-1	1*
Torque and Gears Type, application, and arrangement of gears for transmitting torque. p. C-1	2*
Selective Gear Transmission Types, construction, power flows, and adjustments of a selective gear transmission. Practical exercise on disassembly, inspection, assembly and checking gear and shaft end play, shifting rails, balls, detents, and interlocks of a selective gear transmission. Remove, inspect, replace, and adjust a clutch.	6*
Malfunctions, Selective Gear Transmission, and Clutch Procedures for systematically diagnosing clutch and transmission malfunctions.	1*
Maintenance Problem 1 A practical exercise performing the task listed in maintenance problems 1A through 1E. pp. E-1, E-2 1A. Remove the power pack and separate the transmission (M151, M715, and M809 vehicles). References: TM 9-2320-218-20, TM 9-2320-244-34, TM 9-2320-260-20, TM 9-2320-260-34, TM 9-2320-218-34. (Note	7*

Table 7 (continued)

Course Title and Scope	Hours
References are organizational technical manuals for the respective vehicles.)	
1B. Remove, replace, and adjust the clutch assembly (M151, M715, and M809 vehicles). References: TM 9-2320-218-20, TM 9-2320-244-34, TM 9-2320-260-20, TM 9-2320-260-34, TM 9-2320-218-34. (Note: References include -20 and -34 manuals which indicates a mix of organizational and direct support tasks.)	
1C. Disassembly and assembly of the transmission on the M151 and M715 vehicles. References: TM 9-2320-218-34, TM 9-2320-244-34. (Note: Here tasks go beyond major component removal.)	
1D. Adjust the differential (M151 and M715 vehicles). References: TM 9-2320-218-34, TM 9-2320-244-34. (Note: Tasks are beyond those necessary at organization. Replacement of differential assembly is an organizational task.)	
1E. Disassembly and assembly of the transfer assembly (M151 and M715 vehicles). TM 9-2320-218-20, TM 9-2320-244-34. (Note: The organizational manual for the M151 is again referenced.)	
Maintenance Problem 2	
A practical exercise performing the task listed in maintenance problems 2A through 2E. pp. E-2, E-3	7*
2A. Join and replace power pack (engine, transmission/transfer assemblies) and perform adjustments (M151, M715, and M809). References: TM 9-2320-218-20, TM 9-2320-244-34, TM 9-2320-260-20. (Note: Use of TM 9-2320-218-20 indicates this to be an organizational task for the M151.)	
2B. Remove and replace steering gear assembly (M151, M715, and M809). References: TM 9-2320-218-34, TM 9-2320-244-34, TM 9-2320-260-34. (Note: Use of -34 indicates that this is a direct support unit task for the M151.)	
2C and 2D. Problems do not relate to M151.	

Table 7 (continued)

Course Title and Scope	Hours
2E. Perform engine timing and adjustment (M151, M715, and M809). References: TM 9-2320-218-20, TM 9-2320-260-34. (Note: Use of -20 manual indicates that this is an organizational task for the M151.)	
Maintenance Problem 3 A practical exercise performing the tasks listed in maintenance problems 3A through 3D. pp. E-3, E-4	7*
3A. Test the electrical system using the multimeter and Low Voltage Circuit Tester (M151 and M809). References: TM 9-2320-218-20, TM 9-2320-244-20, TM 9-2320-260-20. (Note: Use of -20 manuals indicates that this is an organizational task.)	
3B. Clean and service air cleaners (M151, M715, M809, and M561). References: TM 9-2320-218-20, TM 9-2320-244-20, TM 9-2320-242-10, TM 9-2320-260-20. (Note: Manuals indicate operator (-10) and organizational (-20) tasks.)	
3C. Does not relate directly to M151.	
3D. Adjust and bleed brakes (M151, M715, and M809). References: TM 9-2320-218-20, TM 9-2320-244-34, TM 9-2320-260-20, TM 9-2320-260-34. (Note: Use of -20 indicates that this is an organizational task for the M151.)	

Findings for Research Question 2

If all the subjects listed from the MOS 63H20, Automotive Repairman Course were added to the MOS 63C20, Track Vehicle Repairman Course without any consolidation, the Track Vehicle Repairman Course would be lengthened by 111 hours plus examinations, or approximately three weeks. There is, however, a degree of duplication among the two programs. Consolidation could reduce the number of hours necessary to

train organizational mechanics to perform major component replacement on the M151A1 ¼-ton truck.

By adding only that instruction that relates directly to the components of the M151A1 (see Table 7 courses marked by *), the MOS 63C20, Track Vehicle Repairman Course would be lengthened by 35 hours or approximately one week.

To obtain an indication of the cost implications of lengthening the track vehicle mechanic course to permit additional training, offices of comptrollers for the U. S. Army Ordnance Center and School and the U. S. Army Armor School were contacted. The following figures were provided from FY 75 course budgetary analyses for both schools.

MOS 63H20, Automotive Repair Course
US Army Ordnance Center and School[4]

Military Personnel, Army (MPA) (Instructors, military support personnel)	$1,961,000
Operation and Maintenance, Army Civilian instructors, supplies and equipment, contract costs	380,900
Total	$2,341,900
Students (FY 75)	1641
Cost per student $\frac{\$2,341,900}{1641} =$	$1,427
Course length	17 weeks, 4 days (17.6 weeks)
Cost per student per week of training $\frac{\$1,427}{17.6} =$	$ 81 (approx)

MOS 63C20, Track Vehicle Mechanic
US Army Armor School[5]

Military Personnel, Army (MPA) (Instructors, military support personnel)	$1,249,000
Operation and Maintenance, Army Civilian instructors, supplies and equipment, other	821,000
Total	$2,070,900
Students (FY 75)	2724
Cost per student $\frac{\$2,070,900}{2724}$ =	$760
Course length	7 weeks
Cost per student per week $\frac{\$\ 760}{7}$ =	$109 (approx)

The cost estimate of providing the assumed additional week of training for replacement of ¼-ton truck major components would be the sum of the student's pay plus the school's costs. Assume that the cost of the additional week would be an average of the current weekly costs for both schools ($95), and that the average student is a Private (E-2) earning $383.40 per month or about $96 per week.[6] Additional costs for one week of training would be $191 ($95 + $96) or $520,284 ($191 x 2724).

RESEARCH HYPOTHESIS

DATA AND FINDINGS

Research Hypothesis

If responsibility for replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies for the M151A1 ¼-ton truck was shifted from direct

support to organizational maintenance level, there would be a significant reduction in direct support maintenance costs.

Tables 8 through 11 display data collected from four simulations of ten runs each varying conditions as shown on each table and previously discussed in Chapter 3. Each run represents one year of operations with a fleet of 28 vehicles. Simulations 1 and 2 are performed assuming an inherent reliability of .98. Fuel and lubricant costs are varied in each simulation. Simulations 3 and 4 assume an inherent reliability of .90 to simulate reliability degradation that could occur during field exercises, combat operations, or periods of severe usage. Again, fuel and lubricant costs are varied for each simulation.

Table 8

Simulation No.	1
Inherent Reliability	.98
Number of Trucks	28
Number of Periods	12
POL Cost/Mile - Wrecker	.376
POL Cost/Mile - M151A1	.041
Test Statistic $t_{.05/11df}$	1.812

Run No.	SPTMIS	GRDDBAR	S	T	Accept/Reject H_o	DSBKDNS	OGFRPTM
1	1	1.1526	.7360	1.5661	Accept	8	Yes
2	10	1.8794	1.0070	1.8664	Reject	8	Yes
3	25	3.0908	1.4906	2.0736	Reject	8	Yes
4	50	5.1098	2.3243	2.1984	Reject	8	Yes
5	100	9.1477	4.0178	2.2768	Reject	8	Yes
6	1	.0808	.0342	2.3633	Reject	8	0.
7	10	.0876	.3417	2.3633	Reject	8	0.
8	25	2.0190	.8543	2.3633	Reject	8	0.
9	50	4.0379	1.7086	2.3633	Reject	8	0.
10	100	8.0579	3.4173	2.3633	Reject	8	0.

Table 9

Simulation No.	2
Inherent Reliability	.98
Number of Trucks	28
Number of Periods	12
POL Cost/Mile - Wrecker	.15
POL Cost/Mile - M151A1	.03
Test Statistic $t_{.05/11df}$	1.812

Run No.	SPTMIS	GRDDBAR	S	T	Accept/Reject H_o	DSBKDNS	OGPRPTM
1	1	1.1410	.7317	1.5594	Accept	8	Yes
2	10	1.7640	.9611	1.8353	Reject	8	Yes
3	25	2.8021	1.3710	2.0439	Reject	8	Yes
4	50	4.5324	2.0807	2.1783	Reject	8	Yes
5	100	7.9930	3.5272	2.2661	Reject	8	Yes
6	1	.0692	.0293	2.3645	Reject	8	0.
7	10	.6921	.2927	2.3645	Reject	8	0.
8	25	1.7303	.7310	2.3645	Reject	8	0.
9	50	3.4606	1.4635	2.3645	Reject	8	0.
10	100	6.9211	2.9271	2.3645	Reject	8	0.

Table 10

Simulation No.	3
Inherent Reliability	.90
Number of Trucks	28
Number of Periods	12
POL Cost/Mile - Wrecker	.376
POL Cost/Mile - M151A1	.041
Test Statistic $t_{.05/11df}$	1.812

Run No.	SPTMIS	GRDDBAR	S	T	Accept/Reject H_o	DSBKDNS	OGPRFTM
1	1	5.7401	.6826	8.4087	Reject	38	Yes
2	10	9.3407	1.0267	9.0626	Reject	38	Yes
3	25	15.2457	1.6888	9.0275	Reject	38	Yes
4	50	25.1473	2.8495	8.8250	Reject	38	Yes
5	100	44.9506	5.2128	8.6232	Reject	38	Yes
6	1	.3961	.0477	8.3106	Reject	38	0.
7	10	3.9607	.4766	8.3106	Reject	38	0.
8	25	9.9016	1.1915	8.3106	Reject	38	0.
9	50	19.8033	2.3829	8.3106	Reject	38	0.
10	100	39.6065	4.7618	8.3106	Reject	38	0.

Table 11

Simulation No.	4
Inherent Reliability	.90
Number of Trucks	28
Number of Periods	12
POL Cost/Mile - Wrecker	.15
POL Cost/Mile - M151A1	.03
Test Statistic $t_{.05/11df}$	1.812

Run No.	SPTMIS	GRDDBAR	S	T	Accept/Reject H_o	DSBKDNS	OGPRPTM
1	1	5.6852	.6783	8.3817	Reject	38	Yes
2	10	8.7562	.9721	9.0077	Reject	38	Yes
3	25	13.8744	1.5396	9.0120	Reject	38	Yes
4	50	22.4047	2.5417	8.8149	Reject	38	Yes
5	100	39.4654	4.5901	8.5979	Reject	38	Yes
6	1	.3412	.0414	8.2407	Reject	38	0.
7	10	3.4121	.4141	8.2407	Reject	38	0.
8	25	8.5304	1.0352	8.2407	Reject	38	0.
9	50	17.0607	2.0703	8.2407	Reject	38	0.
10	100	34.1214	4.1406	8.2407	Reject	38	0.

Findings for the Research Hypothesis

The null hypothesis (H_0) proposes that there is no statistically significant difference in costs generated by the current and proposed direct support maintenance policies for the M151A1 ¼-ton truck. Based on the results of the simulation, with the exception of the condition where the distance to the support unit is one mile, the test statistic for the 95% confidence level is exceeded and the null hypothesis is rejected.

Therefore, it is concluded, based on the results of the simulation, that shifting responsibility for major component replacement for the M151A1 ¼-ton truck from the direct support to the organizational maintenance level would result in statistically significant reductions in direct support maintenance costs.

EVALUATION

Payoff Estimation

An indicator needs to be developed as to the potential worth of adopting the proposed concept. The reader is reminded that the grand means (GRDDBAR) for each run represent mean savings per vehicle per month of operations. Therefore, an estimate of possible savings for the fleet of trucks for that year can be obtained by multiplying the number of trucks by the grand mean and then by the number of months per year. The projected year savings could then be multiplied by twenty-six months, the estimated productive time a mechanic would have in an organization. This figure, compared to training and tool

costs, would be an estimate of the payoff possible from performing major component replacement at the organization.

Figure 2 shows these computations based on Simulation 1, Table 8. Additional training costs per student were computed to be $191 per week (page 63). According to Table of Organization and Equipment (TOE) 07-45H for the Mechanized Infantry Battalion, there are seven tracked vehicle mechanics (MOS 63C20).[7] This would require $1337 (7 x $191) to provide training. Based on Figure 2, savings would have paid for training in twenty-six months if the organization had been 10 miles from the direct support unit. Excluding the factor of organizational preparation time (Runs 6-10), training costs would have been recovered at a 25 mile distance. It is pointed out that if the number of direct support requirements had been higher as in Simulation 3, Table 10, both training and tool costs would have been quickly repaid.

Figure 2

Simulation No.	1
Inherent Reliability	.98
Number of Trucks	28
Number of Periods	12
Direct Support Requirements	8

Run	SPTMIS	GRDDBAR	Estimated 1 Year Savings ($)	Estimated 26 Months Savings ($)
1	1	1.1526	387	839
2	10	1.8794	631	1368
3	25	3.0908	1038	2250
4	50	5.1098	1717	3720
5	100	9.1477	3074	6660
6	1	.0808	27	59
7	10	.8076	271	588
8	25	2.0190	678	1470
9	50	4.0379	1357	2940
10	100	8.0579	2713	5879

Limitations

This simulation is useful as a vehicle to define factors influencing direct support maintenance costs. If people can agree on the elements that make up the model, then problem areas for examination can be isolated. If a model element is controversial, this situation provides a basis for redefinition and further test.

The elements of this model are controversial. Statistical distributions are used to generate maintenance actions because the actual data leading to the Sample Data Collection Analysis Report was not available.

There is no simulation of resupply operations. Probabilities that a breakdown will occur should be based on vehicle age to obtain a more accurate representation of reality. Estimates were used for such items as the minimum and maximum component replacement times.

Finally, the use of the concept of organizational preparation time (OGPRPTM) can be questioned. This is time required to prepare a vehicle for acceptance by the direct support unit. Direct support unit personnel perform a technical inspection to verify that all organizational maintenance has been performed, to assure that the vehicle and equipment stored on the vehicle are completed, and to serve as a starting point for troubleshooting. These are necessary functions that would have to be performed regardless of who was responsible for maintenance. It is the author's belief, however, that transfer of a vehicle from one unit to another

creates a problem in accountability that requires that the vehicle be thoroughly inspected. Additionally, the owning unit should know the vehicle thoroughly and detailed inspection need not be a prerequisite to correcting a problem.

SUMMARY

This chapter has displayed findings in regard to the research questions and hypotheses. Tool requirements to enable organizations to perform major component replacement on the M151A1 ¼-ton truck were identified and a cost per battalion for those tools was estimated. Training programs for the direct support unit and organizational mechanics were compared and an estimate of additional training costs was provided. Finally, based on simulation results, it was concluded that moving direct support major component replacement responsibilities forward to organizational level resulted in significant decreases in direct support maintenance costs.

CHAPTER 4

FOOTNOTES

1. Program of Instruction, Track Vehicle Mechanic Course, MOS: 63C20 (Aberdeen Proving Ground, Maryland: U. S. Army Ordnance Center and School, 16 August 1974), pp. 2-5.

2. U. S. Army Catalog Data Agency, Army Master Data File (New Cumberland, Pennsylvania: December, 1974), p. 45.

3. U. S. Army Catalog Data Agency, Army Master Data File (New Cumberland, Pennsylvania: December, 1974), p. 31.

4. Telephonic conversation with Mr. Robert Fulkerson, Office of Management and Budget, U. S. Army Ordnance Center and School, Aberdeen, Maryland, 1975.

5. Telephonic conversation with CPT David Wilkins, Office of the Comptroller, U. S. Army Armor Center, Fort Knox, Kentucky.

6. Military Pay Section, Finance and Accounting Office, U. S. Army Combined Arms Center and Fort Leavenworth, 7 May 1975.

7. TOE 07-45H, p. II-17.

CHAPTER 5

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

SUMMARY

Problem

The general problem studied was the feasibility of moving direct support maintenance responsibilities forward to the organizational maintenance level. The current concept relies on centralization of skills and capital equipment such as tools and test equipment. This is a viable concept when the price of facilities is high relative to labor. In recent years, however, labor has become an extremely high priced commodity and using people in such tasks as driving to maintenance units frequently to deliver and pick up equipment is inefficient. Thus, when equipment is high priced, complex, cumbersome and requires highly specialized skills such as certain missile system support equipment, a central maintenance facility is economical. If, however, tools are cheap versus the cost of people, then perhaps the tools should be proliferated to increase the productivity of people.

Flexibility, then, is required in the study of the problem of providing direct support. This study proposes that allocation of maintenance responsibilities should be based on the particular equipment being supported as opposed to applying one concept to all commodities. This study develops a

methodology for analysis of individual items of automotive materiel. The vehicle for analysis is the M151A1 ¼-ton truck. The intent of the model and methodology is to permit analysis of more complex automotive items in order to obtain a more optimum allocation of maintenance responsibility.

Two research questions were examined:

1. What are tool and equipment costs incurred by moving responsibility for replacement of engines, transmissions/transfer assemblies, clutches, and steering gear assemblies forward to the using organization for the M151A1 ¼-ton truck?

2. What are the costs associated with providing additional skills at the organizational level to permit replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies?

The research hypothesis examined was:

If responsibility for replacement of engines, transmission/transfer assemblies, clutches, and steering gear assemblies was shifted from direct support to organizational maintenance level, there would be a significant reduction in direct support maintenance costs.

Methodology

The maintenance allocation chart for the M151 series of trucks was reviewed to determine what component replacement was a direct support responsibility. The engine, transmission/transfer assembly, clutch, steering gear, and oil pump must be replaced by the direct support unit. Oil pump replacement was not examined since the data base for the study showed that for 208 vehicles operated over 5,000,000 miles, no oil pump replacements were recorded.

Tool Costs. Tool costs were estimated by reviewing the direct and general support maintenance manual to determine

what tools are required to replace the above components. The organizational maintenance shop set (no. 2 Common) was used to determine if those tools are on hand at organizational level. The Army Master Data File was used to determine the price of tools that would have to be provided if major component replacement responsibility for the M151 was given to the organizational level.

Training Costs. The programs of instruction for MOS 63H20, Automotive Repairman (direct and general support) and MOS 63C20, Tracked Vehicle Mechanic (organizational) were compared to determine what field maintenance training would have to be given organizational mechanics to permit them to replace M151 series major components.

Variable Costs. A computer simulation was used to simulate direct support maintenance requirements generated by ¼-ton trucks organic to a mechanized infantry battalion. Models for direct and indirect costs were developed to describe the current maintenance concept where vehicles are taken to the direct support unit for repair and the proposed concept where component replacement would be done at and by the organizational level.

Current concept model:

ATOTCST = (OGPRPTM + TRANSTM + DSMNTM)*6.48 + APOLCST

where

ATOTCST = Total maintenance costs generated by the current concept (Concept A)

OGPRPTM = Time required to prepare a vehicle for acceptance by the direct support unit

TRANSTM = Time required to transport the disabled vehicle to and from the direct support unit

DSMNTM = Time required to replace the component

6.48 = Hourly labor rate (USAREUR, 1974)

Proposed concept model:

BTOTCST = DSMNTM*6.48

where OGPRPTM and TRANSTM are assumed to be zero due to repairs being accomplished by the owning unit.

Results

Tools. Tools required by the organization consisted of the engine/transmission removal sling. An optional item would be the automotive hoist. Estimated costs are $150-$300 per battalion.

Training. Additional training would be 35 hours at a cost of approximately $191 per student (MOS 63C20). For a mechanized infantry battalion currently authorized 7 such mechanics, the cost would be approximately $1,337.

Variable Costs. The computer simulation and the statistical test showed that cost savings under the proposed concept were statistically significant. Comparison of these savings to tool and training costs showed that the additional investment would have a high payoff, especially in situations where there was a large distance between the user and the support unit or where conditions increased normal maintenance requirements.

CONCLUSIONS

The significance of the study findings is that they provide a basis for a systematic examination of an aspect of maintenance doctrine from a different viewpoint. The concept of increased maintenance responsibility forward is not new; but fixed personnel ceilings and increased battlefield lethality give new impetus to the examination.

Potential benefits are many. Emphasis on increased automotive maintenance forward could lead to a reduction in the size of the maintenance battalion. It could serve to reduce the vulnerability of extended support complexes in brigade, division, and corps rear areas. The need to move major items around the battlefield would be reduced, which is particularly desirable if there is air purity. Finally, there is a potential for faster response to user requirements, incentives to upgrade maintenance management capability in forward units, and more efficient use of people.

RECOMMENDATIONS

The methodology should be applied to other tactical vehicles such as the $1\frac{1}{4}$-ton, $2\frac{1}{2}$-ton, and 5-ton trucks to ascertain the feasibility of increased maintenance forward for the class of tactical vehicles. It is recommended that, if possible, the study should include an actual troop test to assess the concept in an operational environment.

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APPENDIX A

COMPUTER SIMULATION

VARIABLE NAMES

Variable	Description
A	Dummy argument for internal random number generator function (RANF(A)
AMNTTIM(N)	Collective time associated with direct support maintenance for the Nth truck
APOLCST(N)	Total POL cost for the Nth truck under the current maintenance concept
ASSY	Used in routine to select component that causes an unscheduled direct support maintenance requirement
ATIMCST(M)	Sum of total monthly costs for vehicle (M) for the entire period simulated for the current maintenance concept
ATOTCST(N)	Total direct support maintenance time x hourly labor cost ($6.48) + total POL cost for the Nth truck
ATOTIME(M)	Total maintenance time under the current concept for vehicle (M) for the period simulated
ATOTPOL(M)	Total fuel and lubricant costs (M) under the current concept for vehicle (M) for the period simulated
BMNTTIM(N)	Total direct support maintenance time under the proposed concept
BPOLCST(N)	Total POL cost for the Nth truck under the proposed concept. In this simulation, BPOLCST(N) is always zero because maintenance is performed in the battalion area.
BTIMCST(M)	Sum of total monthly costs for vehicle (M) for entire period simulated for the proposed maintenance concept
BTOTCST(N)	Total direct support maintenance time x hourly labor cost ($6.48) + BPOLCST (=0) for the Nth vehicle
BTOTIME(M)	Total maintenance time under the proposed concept for vehicle (M) for the period simulated
BTOTPOL(M)	Total fuel and lubricant costs under the current concept for vehicle (M) for the period simulated
CLUTCH	Exponentially distributed clutch replacement time generated by FUNCTION CLUTCH (Dummy)

Variable	Description
DBAR	SUMDIFF/XDAYS. Monthly mean cost difference between the two concepts. Used to compute the mean of the monthly mean differences (grand mean)
DEVSQR(J)	Squared deviations between the monthly mean cost differences and the grand mean for the Jth month
DIFF(N)	ATOTCST(N) - BTOTCST(N) for each vehicle. Difference in total monthly maintenance costs generated by the current (Concept A) and proposed (Concept B) concepts
DSBKDNS	The number of unscheduled direct support maintenance requirements for all trucks for the period simulated
DSMNTM	Exponentially distributed time to replace engine, transmission, clutch, steering gear, or other component at direct support unit level
ENGINE	Exponentially distributed engine replacement time generated by FUNCTION ENGINE (Dummy)
EXPTIM	Exponentially distributed time value to perform maintenance task on selected components
FRMCOST	Petroleum, oil, and lubricant cost to go to the direct support unit, pick up a repaired truck, and return
FRMTIM1, FRMTIM2	Time to go to a direct support unit, pick up a repaired vehicle, and return home. Assumed to require two people
GRDDBAR	SUM DBAR/XMONTH. Mean of monthly means (grand mean)
ISEED	Seed for random number generator
N	Used in routine to select a truck; a test for occurrence of unscheduled maintenance requirements
NMONTHS	Number of a given month. Each month contains 21 working days.
NPERIOD	Total number of months to be simulated
NTRUCKS	Number of trucks in organization

Variable	Description
OGMNTM(N)	Sum of hours of unscheduled organizational maintenance (OTSKTM)
OGPRPTM	Exponentially distributed organizational preparation time required to pass direct support unit inspection requirements (assume 8.0 hours average per vehicle)
OTHER	Exponentially distributed time value to perform direct support maintenance task other than engine, transmission/transfer, clutch, and steering gear assembly replacement
OTSKTM	Normally distributed time to perform an unscheduled organizational maintenance task
POLCPM1	Petroleum, oil, and lubricant costs per mile for the 5-ton wrecker. Based on FM 101-10-1, POLCPM1 = $.15. Based on the Research Analysis Corporation Study, POLCPM1 = $.376
POLCPM2	Petroleum, oil, and lubricant costs per mile for the ¼-ton truck. Based on FM 101-10-1, POLCPM2 = $.03. Based on the Research Analysis Corporation study, POLCPM2 = $.041
POLCST	Cost of gasoline to transport disabled vehicle and drivers to the direct support unit
RANF(A)	Internal function used to generate pseudo-random numbers
RANSET	Name of computer library routine to provide a recurring sequence of random numbers to assure that each variable change in the simulation is tested under the same conditions
RNORM	Value of the normally distributed random variable used to compute organizational task time (OTSKTM)
S	Standard deviation of monthly mean differences
SPTMIS	Distance to direct support unit
STEERG	Exponentially distributed steering gear assembly replacement time generated by FUNCTION STEERG (Dummy)
Subroutine CURRENT	Subroutine testing current maintenance concept and developing associated time and costs

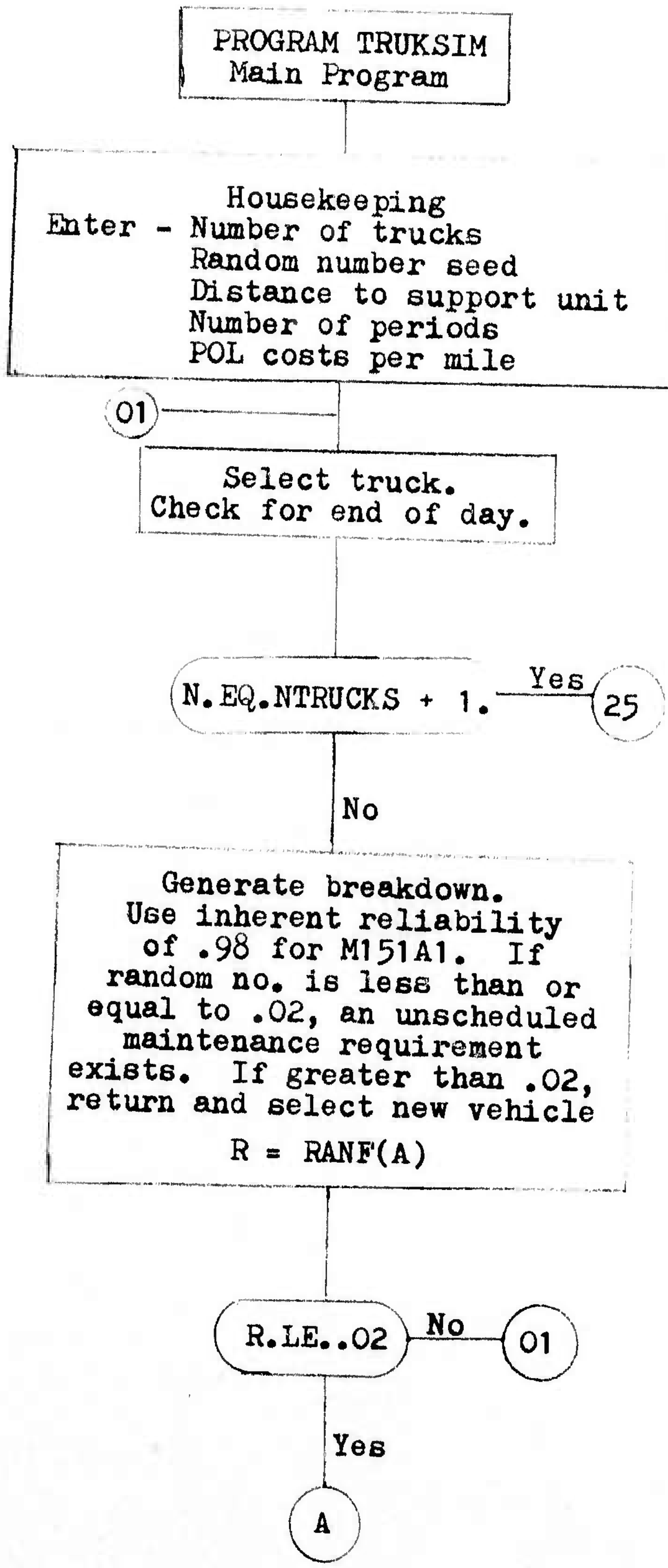
Variable	Description
Subroutine PROPOSD	Subroutine testing propcsed maintenance concept and developing associated time and costs
Subroutine STATSUM	Computes and prints summary statics
SUMDBAR	Sum of monthly mean cost differences between costs generated under each concept for each truck
SUMDIFF	Sum of monthly cost differences between costs generated under each concept for each truck
SUMDVSQ	Sum of monthly squared deviations DEVSQR(J) between the monthly mean cost differences and the simulation grand mean. Used to compute the standard deviation, S
T	"t" statistic computed to test the statistical significance of the mean difference in maintenance costs of the two maintenance concepts
TOCOST	Petroleum, oil, and lubricant costs to transport a disabled vehicle to the direct support unit, leave the vehicle, and return using a 5-ton wrecker
TOTDAYS	Total days in simulation
TOTIM1, TOTIM2	Time required to transport a disabled vehicle to the direct support unit and return. Assumed to require two people
TOTTIM	Subroutine CURRENT - sum of organizational preparation time for direct support maintenance; transportation time to the direct support unit and time to perform the direct support maintenance task Subroutine PROPOSD - total time to perform the direct support maintenance task. Organizational preparation time and transportation time are not included because maintenance is performed in the battalion area
TRANSM	Exponentially distributed transmission replacement time generated by FUNCTION TRANSM (Dummy)
TRANSTM	Total transportation time required to complete repairs for a particular direct support requirement. Vehicle transportation time is multiplied by the number of people making the trips (4)

Variable	Description
U1, U2	Uniformly distributed random variables used to
XDAYS	Number of days in month (21 working days)
XMONTHS	Floating point number of months to permit grand mean, standard deviation, and "t" statistic computation
XMU	Mean of exponential distribution
XTRUCKS	Floating point number of trucks to permit computation of monthly mean cost differences (DBAR)

APPENDIX B

COMPUTER SIMULATION

FLOWCHART


PROGRAM TRUKSIM
Main Program
Housekeeping
Enter - Number of trucks
Random number seed
Distance to support unit
Number of periods
POL costs per mile
01
Select truck.
Check for end of day.
N.EQ.NTRUCKS + 1.
Yes
25
No
Generate breakdown.
Use inherent reliability of .98 for M151A1. If random no. is less than or equal to .02, an unscheduled maintenance requirement exists. If greater than .02, return and select new vehicle
R = RANF(A)
R.LE..02
No
01
Yes
A

A

Determine if the unscheduled maintenance requirement is direct support or organizational maintenance. If the random number is greater than .0583, the requirement is organizational. Generate an organizational maintenance time and return to select a new truck.

R = RANF(A)

R.LE.0583

No

OGMNTM(N) = OGMNTM(N) + OTSKTM (DUMMY)

01

Yes

Add one to no. of direct support requirements.

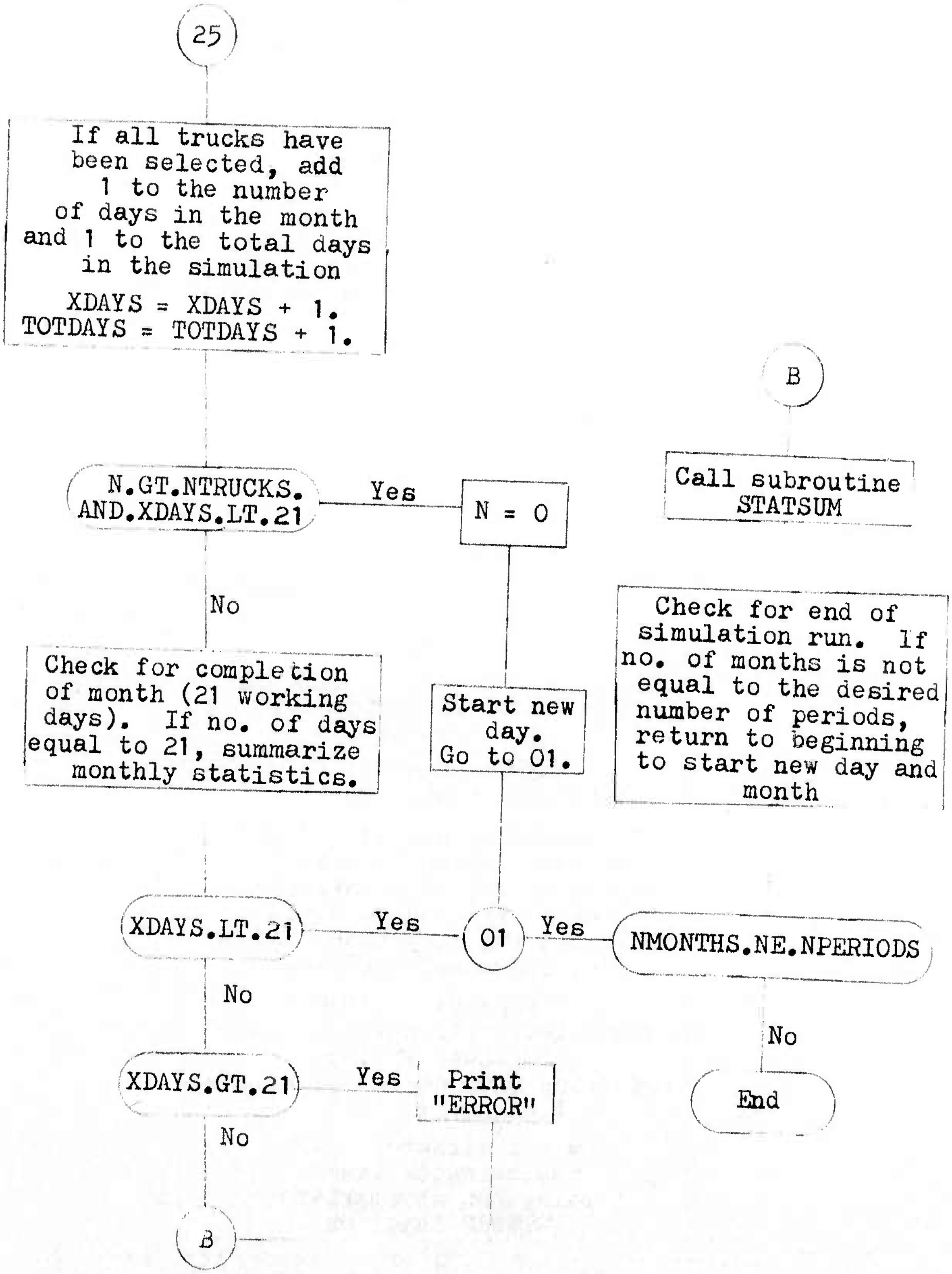
ASSY = RANF(A)
DSBKDNS = DSBKDNS + 1.

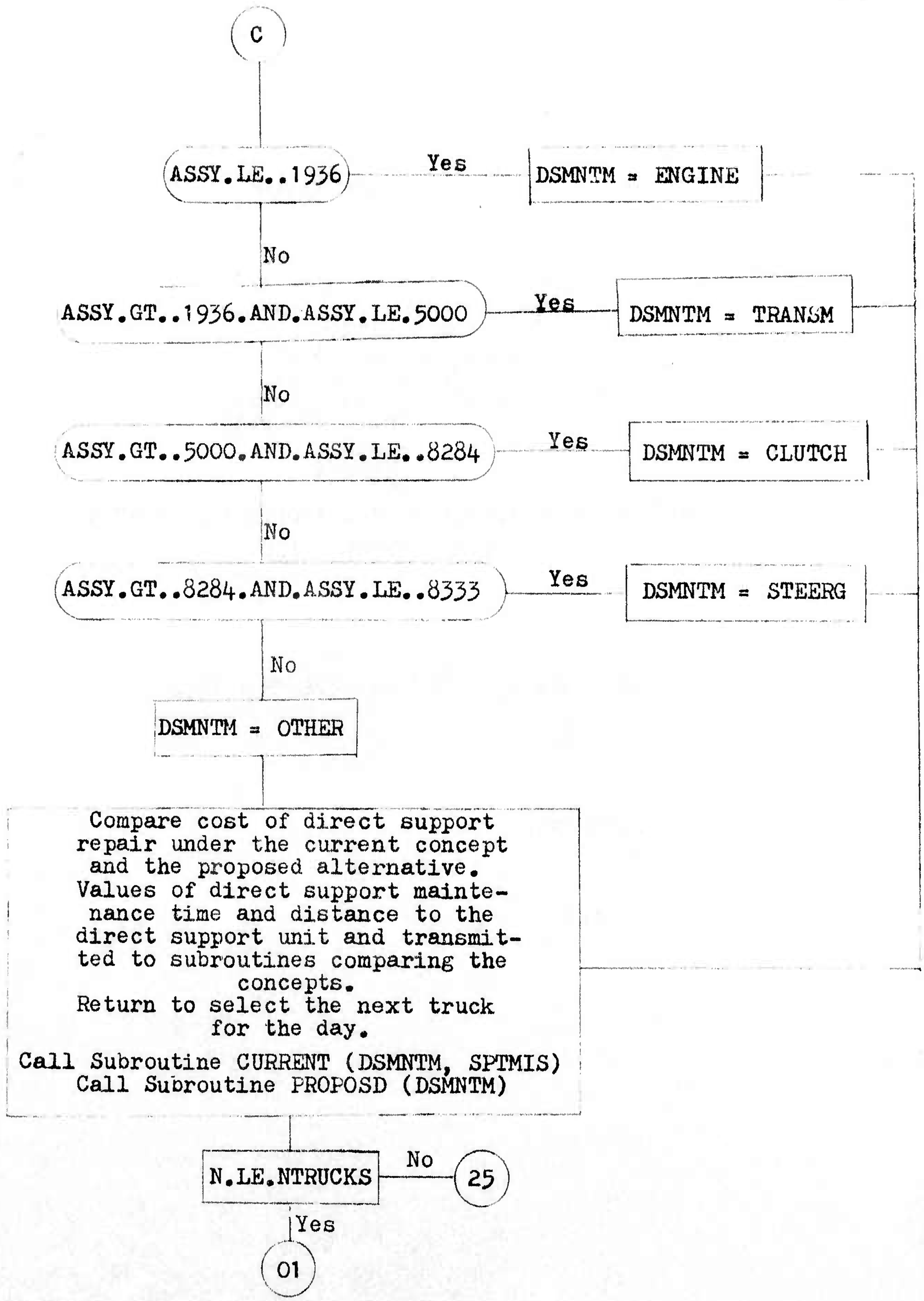
DS breakdown has occurred. Determine which component failed by use of a uniformly distributed random number corresponding to probabilities of component failure.

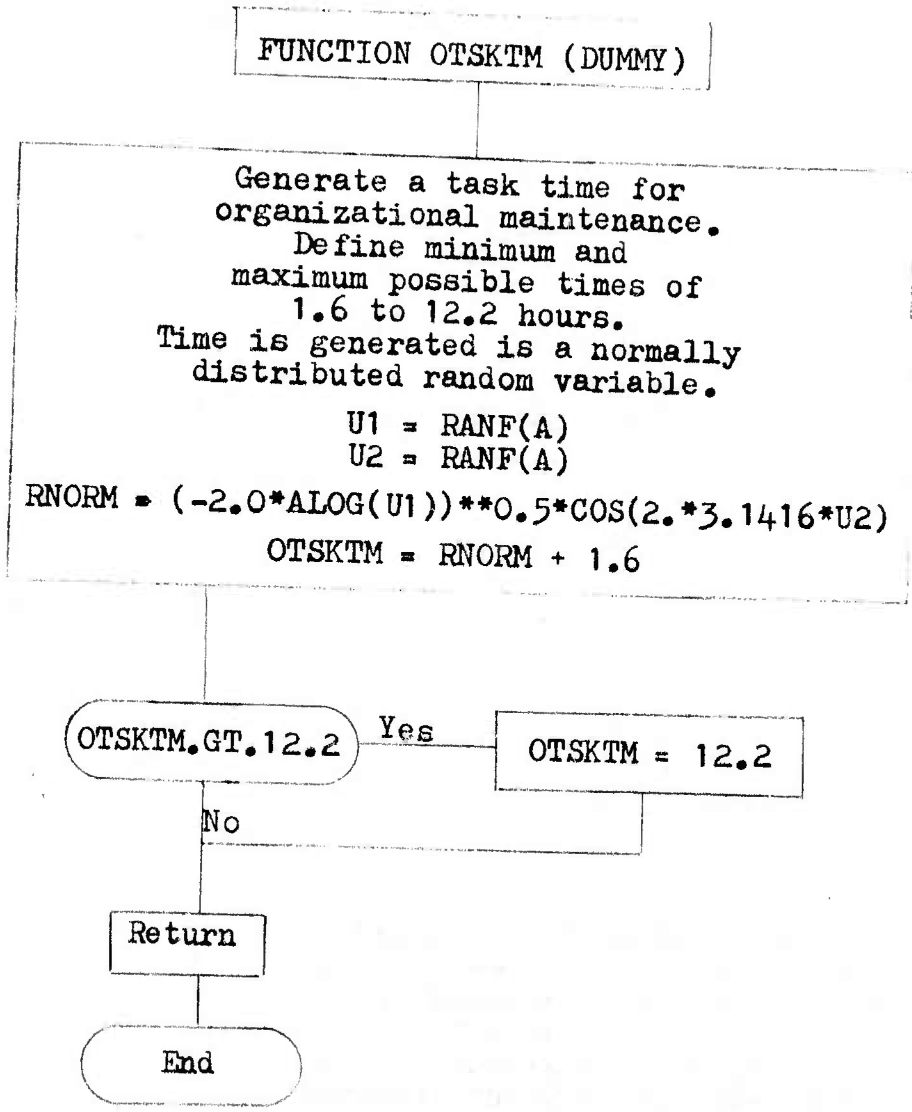
P(Engine) = .1936
P(Transmission/Transfer) = .3064
P(Clutch) = .3284
P(Steering Gear Assembly) = .0049
P(Other) = .1667

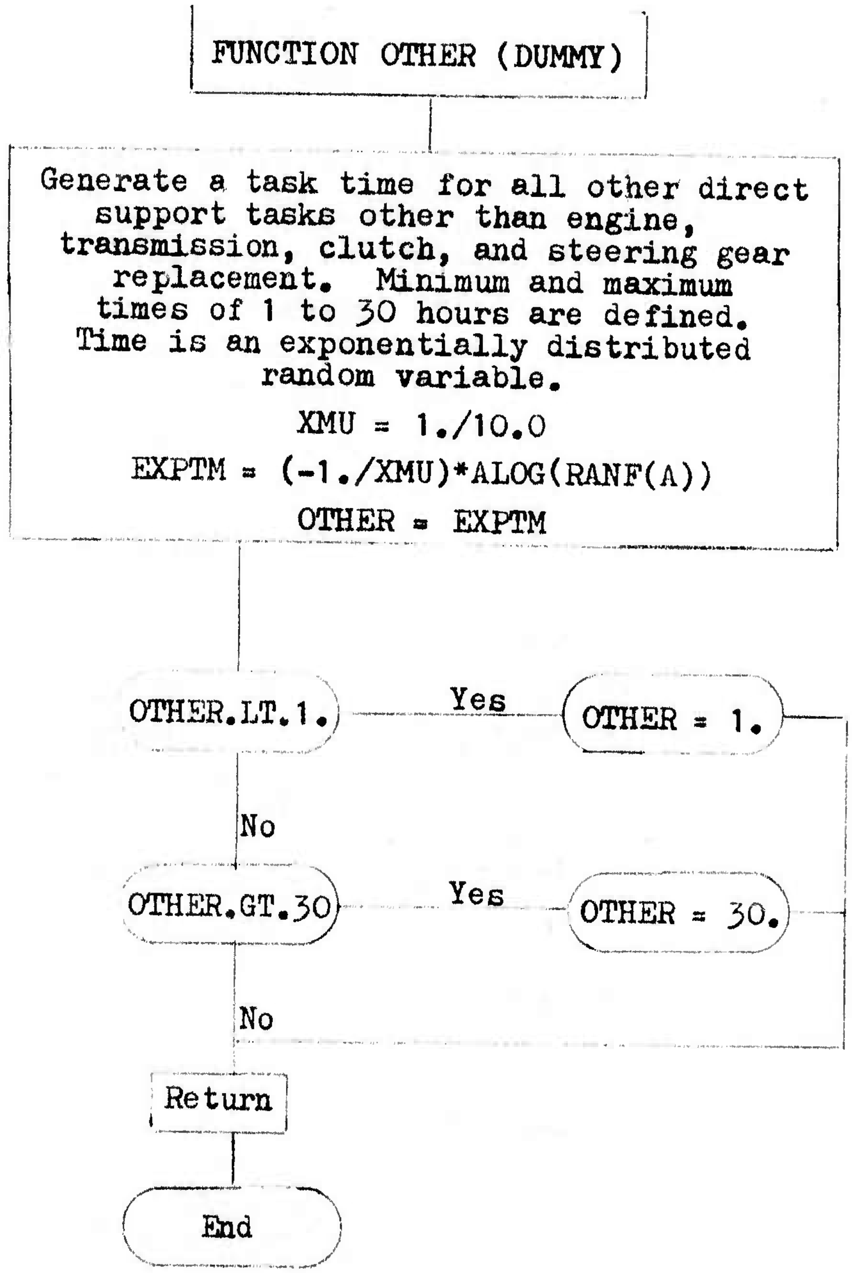
Compute direct support maintenance time using the appropriate FORTRAN function

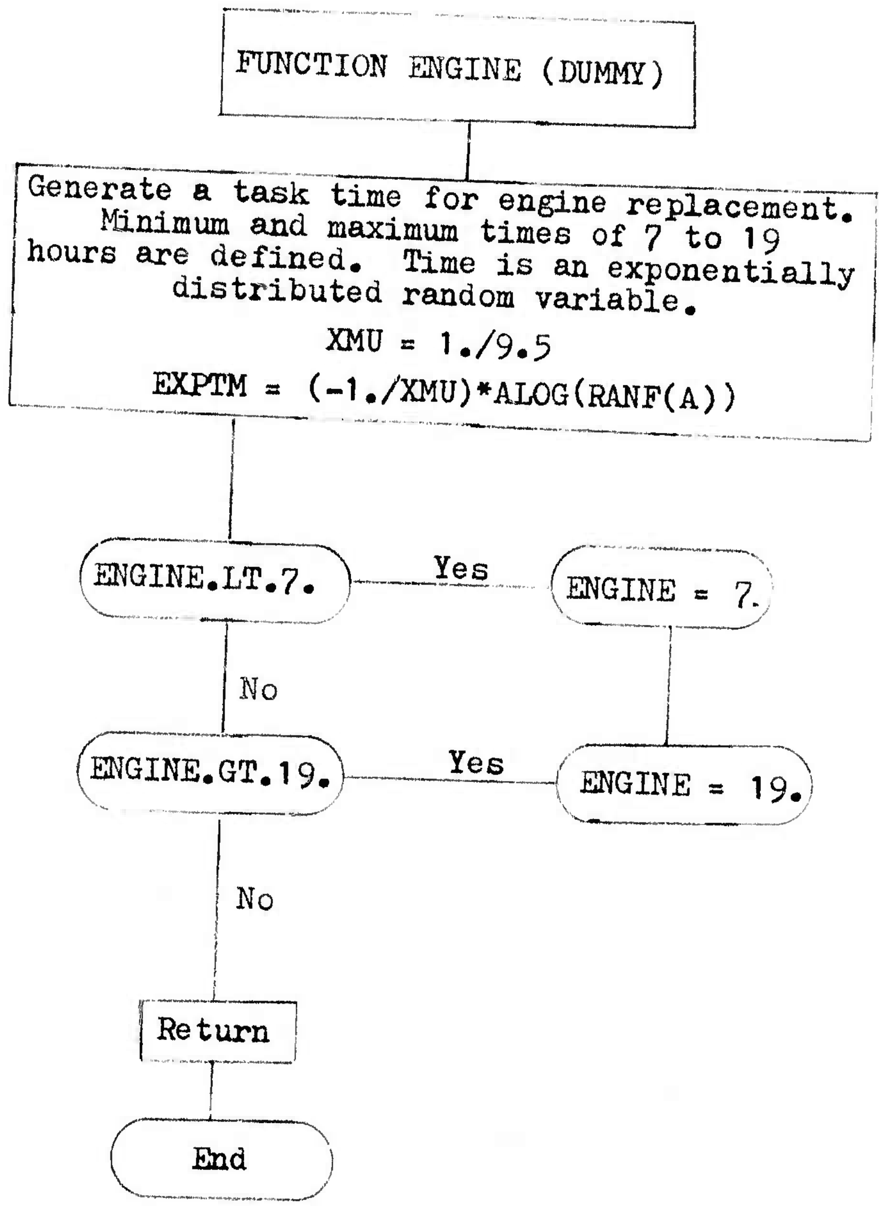
C


25
If all trucks have been selected, add 1 to the number of days in the month and 1 to the total days in the simulation
XDAYS = XDAYS + 1.
TOTDAYS = TOTDAYS + 1.
N.GT.NTRUCKS. AND.XDAYS.LT.21
Yes
N = 0
No
Check for completion of month (21 working days). If no. of days equal to 21, summarize monthly statistics.
Start new day. Go to 01.
XDAYS.LT.21
Yes
01
No
XDAYS.GT.21
Yes
Print "ERROR"
No
B
B
Call subroutine STATSUM
Check for end of simulation run. If no. of months is not equal to the desired number of periods, return to beginning to start new day and month
Yes
NMONTHS.NE.NPERIODS
No
End

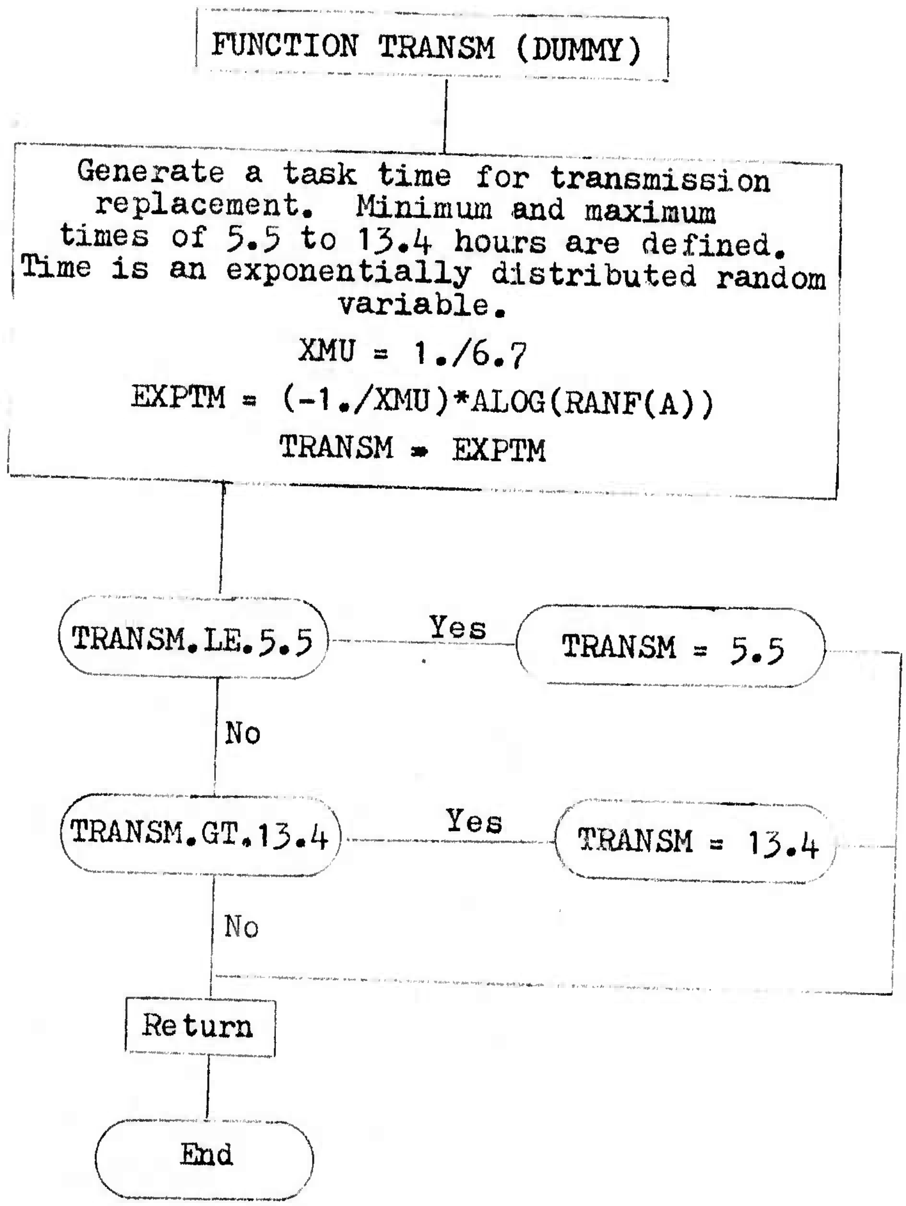

C
ASSY.LE..1936
Yes
DSMNTM = ENGINE
No
ASSY.GT..1936.AND.ASSY.LE.5000
Yes
DSMNTM = TRANSM
No
ASSY.GT..5000.AND.ASSY.LE..8284
Yes
DSMNTM = CLUTCH
No
ASSY.GT..8284.AND.ASSY.LE..8333
Yes
DSMNTM = STEERG
No
DSMNTM = OTHER
Compare cost of direct support repair under the current concept and the proposed alternative. Values of direct support maintenance time and distance to the direct support unit and transmitted to subroutines comparing the concepts. Return to select the next truck for the day.
Call Subroutine CURRENT (DSMNTM, SPTMIS)
Call Subroutine PROPOSD (DSMNTM)
N.LE.NTRUCKS
No
25
Yes
01

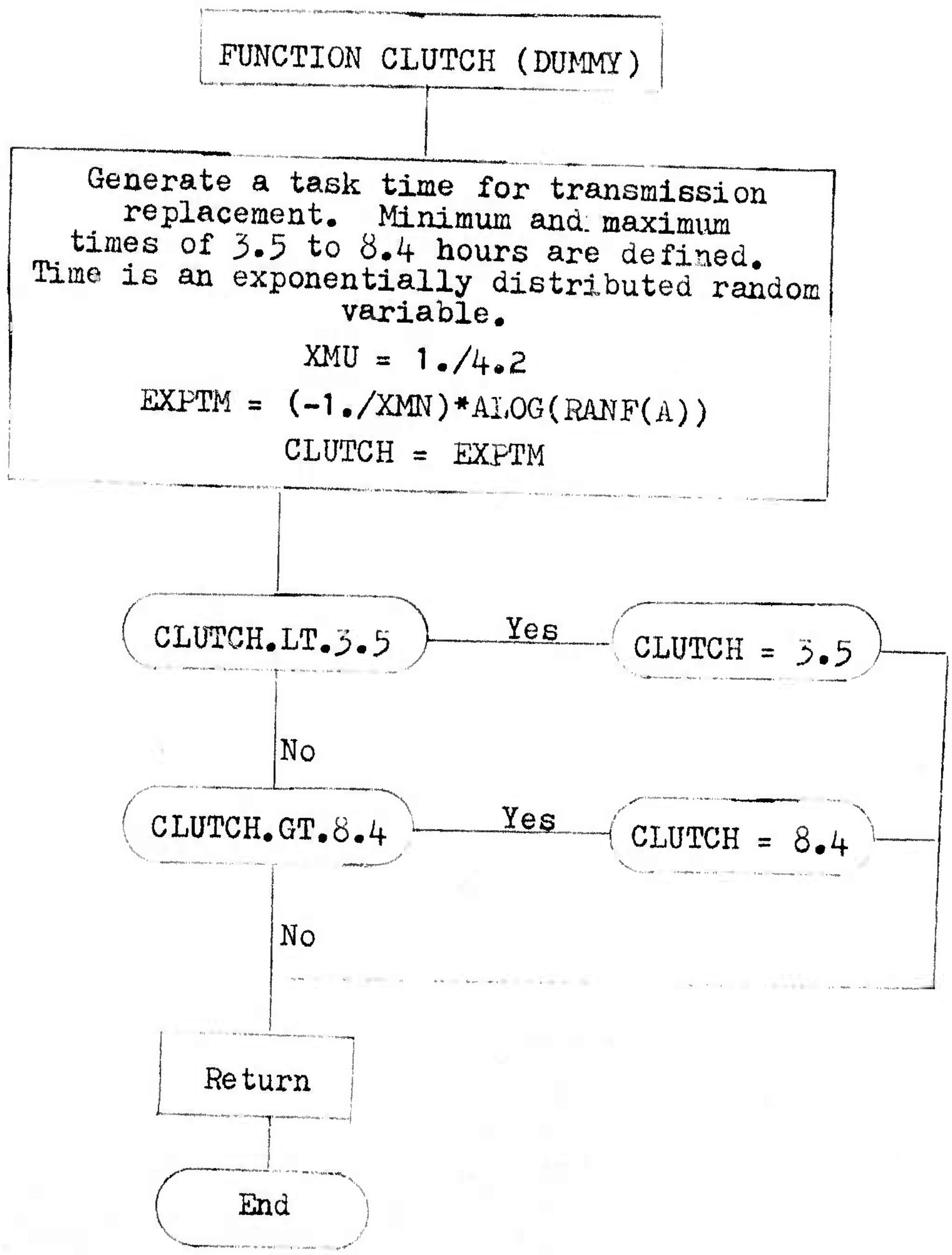

FUNCTION OTSKTM (DUMMY)
Generate a task time for organizational maintenance. Define minimum and maximum possible times of 1.6 to 12.2 hours. Time is generated is a normally distributed random variable.
U1 = RANF(A)
U2 = RANF(A)
RNORM = (-2.0*ALOG(U1))**0.5*COS(2.*3.1416*U2)
OTSKTM = RNORM + 1.6
OTSKTM.GT.12.2
Yes
OTSKTM = 12.2
No
Return
End


FUNCTION OTHER (DUMMY)
Generate a task time for all other direct support tasks other than engine, transmission, clutch, and steering gear replacement. Minimum and maximum times of 1 to 30 hours are defined. Time is an exponentially distributed random variable.
XMU = 1./10.0
EXPTM = (-1./XMU)*ALOG(RANF(A))
OTHER = EXPTM
OTHER.LT.1.
Yes
OTHER = 1.
No
OTHER.GT.30
Yes
OTHER = 30.
No
Return
End

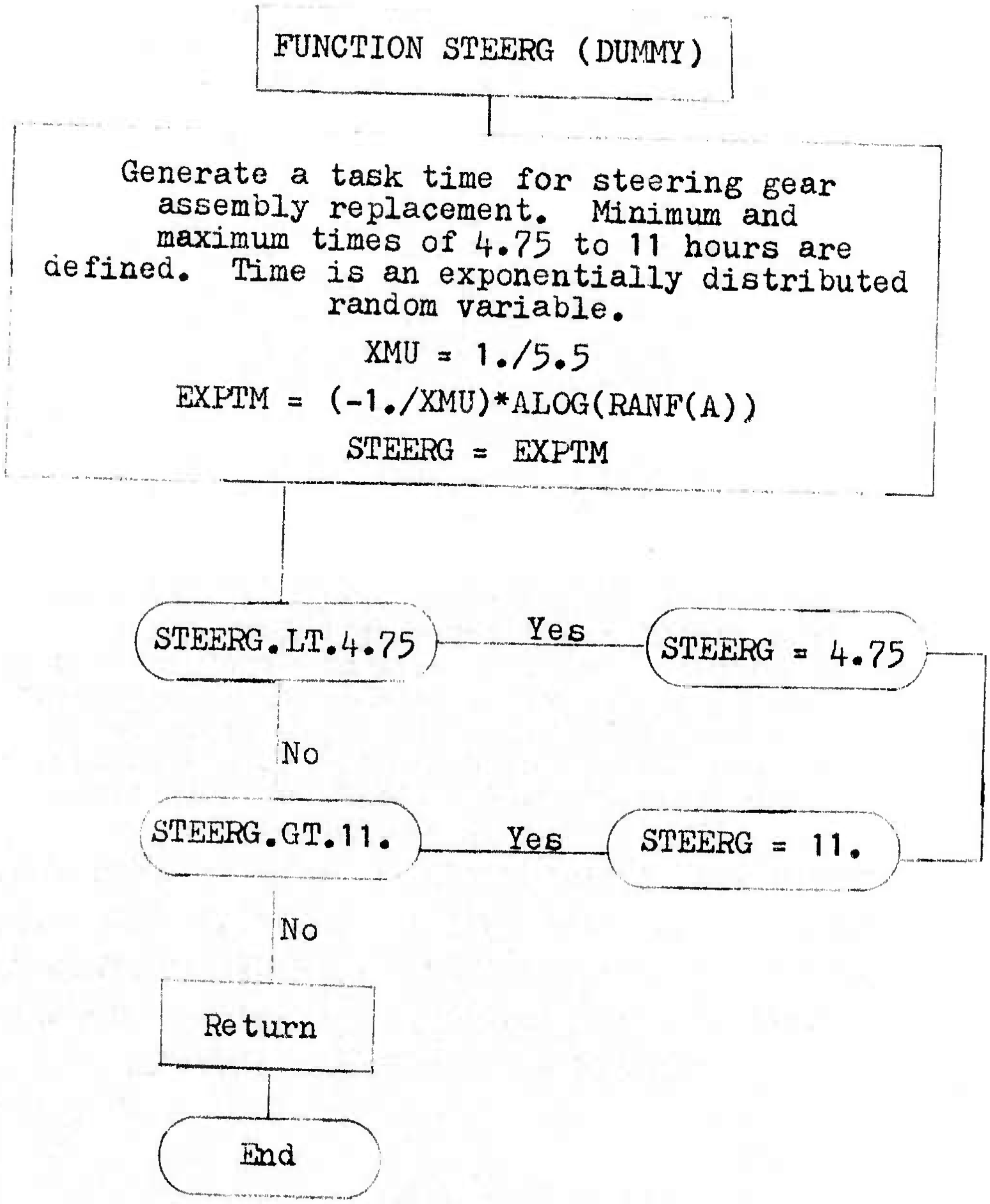


FUNCTION ENGINE (DUMMY)
Generate a task time for engine replacement. Minimum and maximum times of 7 to 19 hours are defined. Time is an exponentially distributed random variable.
XMU = 1./9.5
EXPTM = (-1./XMU)*ALOG(RANF(A))
ENGINE.LT.7.
Yes
ENGINE = 7.
No
ENGINE.GT.19.
Yes
ENGINE = 19.
No
Return
End


FUNCTION TRANSM (DUMMY)
Generate a task time for transmission replacement. Minimum and maximum times of 5.5 to 13.4 hours are defined. Time is an exponentially distributed random variable.
XMU = 1./6.7
EXPTM = (-1./XMU)*ALOG(RANF(A))
TRANSM = EXPTM
TRANSM.LE.5.5
Yes
TRANSM = 5.5
No
TRANSM.GT.13.4
Yes
TRANSM = 13.4
No
Return
End



FUNCTION CLUTCH (DUMMY)
Generate a task time for transmission replacement. Minimum and maximum times of 3.5 to 8.4 hours are defined. Time is an exponentially distributed random variable.
XMU = 1./4.2
EXPTM = (-1./XMN)*ALOG(RANF(A))
CLUTCH = EXPTM
CLUTCH.LT.3.5
Yes
CLUTCH = 3.5
No
CLUTCH.GT.8.4
Yes
CLUTCH = 8.4
No
Return
End


FUNCTION STEERG (DUMMY)
Generate a task time for steering gear assembly replacement. Minimum and maximum times of 4.75 to 11 hours are defined. Time is an exponentially distributed random variable.
XMU = 1./5.5
EXPTM = (-1./XMU)*ALOG(RANF(A))
STEERG = EXPTM
STEERG.LT.4.75
Yes
STEERG = 4.75
No
STEERG.GT.11.
Yes
STEERG = 11.
No
Return
End

SUBROUTINE CURRENT (DSMNTM,SPTMIS)

Subroutine computes monthly direct support maintenance costs for each truck under the current concept

Generate a task time to accomplish all organizational maintenance per FM 38-5, Logistics Maintenance Management, prior to acceptance by the direct support unit.

```
XMU = 1./8.0
OGPRPTM = (-1./XMU)*ALOG(RANF(A))
```

Generate a transportation time to and return from the direct support unit assuming use of a wrecker. Generate a transportation time to pick up the repaired vehicle from the direct support unit using one ¼-ton truck to go to the DSU and return using both vehicles. Two operators are assumed for both trips (total of four people)

```
TOTIM1 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
TOTIM2 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
FRMTIM1 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
FRMTIM2 = (.75*SPTMIS/25.) + (RANF(A)*SPTMIS/25.)
TRANSTM = 4.*(TOTIME + FRMTIME)
```

D

D

Compute total time by summing organizational preparation time, transport time, and direct support maintenance time. For some simulation runs, organizational time is set to zero.

OGPRPTM = 0.

TOTTIM = OGPRPTM + TRANSTM + DSMNTM

Compute total direct and indirect maintenance time for each truck.

AMNTTIM(N) = AMNTTIM(N) + TOTTIM

Compute petroleum, oil, lubrication (POL) costs for each truck as a function of the distance to the direct support unit, POL cost per mile based on tables in FM 101-10-1 or in the Research Analysis Corporation study on Army fuel costs, and the number of trips to or from the direct support unit.

TOCOST = SPTMIS*POLCPM1*2.

FRMCOST = 3.*SPTMIS*POLCPM2

POLCST = TOCOST + FRMCOST

APOLCST(N) = APOLCST(N) + POLCST

Compute total costs per vehicle by summing the product of maintenance time for the task and the hourly labor rate plus the POL cost generated by the task and adding to the total costs existing on the Nth truck

ATOTCST(N) = AMNTTIM(N)*6.48 + APOLCST(N)

Return

End

Subroutine PROPOSD

Computes monthly direct support maintenance costs for each truck under the proposed concept.

Total maintenance time for component replacement is that time related directly to the maintenance task. No organizational preparation time or transportation time is computed since the component replacement takes place in the organizational maintenance area. The time is added to the existing monthly total for the Nth truck.

TOTTIM = DSMNTM

BMNTTIM(N) = BMNTTIM(N) + TOTTIM

POL costs to transport the disabled vehicle to the direct support unit are zero. Provision is made in the program for POL costs if required.

BPOLCST(N) = 0.

Total monthly costs for the vehicles are computed by adding the product of the maintenance time and the hourly labor rate and the POL cost (0) to the existing monthly cost for the vehicle.

BTOTCST = BMNTTIM(N)*6.48 + BPOLCST(N)

Return

End

Subroutine STATSUM

Computes monthly and simulation totals. Variables are re-initialized. Computes monthly mean costs, mean of monthly mean costs differences for each concept, the standard deviation of the monthly mean costs, and the "t-statistic" to test for statistical significance of the differences in monthly mean costs

For the end-of-month computation, add 1 to the number of months.

```
NMONTHS = NMONTHS + 1
```

Begin preparations of the test for significance of the difference in the means of two populations by computing the difference in maintenance costs per truck per month under each concept.

```
    DO 400 K = 1,NTRUCKS
400 DIFF(K) = ATOTCST(K) - BTOTCST(K)
```

Sum differences for each truck. Convert NTRUCKS to floating point variable.

```
    DO 500 L = 1,NTRUCKS
500 SUMDIFF = SUMDIFF + DIFF(L)
    XTRUCKS = NTRUCKS
```

E

E

Compute the mean differences in monthly costs per truck per month and store so that the average difference for each month is maintained. The sum of the differences is then set to zero to permit computations for the next month.

```
DBAR(NMONTHS) = SUMDIFF/XTRUCKS
SUMDIFF = 0.
```

Monthly cost, time, and POL computations are added to previous totals to collect statistics for the entire time of the simulation. "M" is the number of the truck.

```
    DO 650 M = 1,NTRUCKS
    ATIMCST(M) = ATIMCST(M) + ATOTEST(M)
    BTIMCST(M) = BTIMCST(M) + BTOTCST(M)
    ATOTIME(M) = ATOTIME(M) + AMNTTIM(M)
    BTOTIME(M) = BTOTIME(M) + BMNTTIM(M)
    ATOTPOL(M) = ATOTPOL(M) + APOLCST(M)
650 BTOTPOL(M) = BTOTPOL(M) + BPOLCST(M)
```

Reinitialize monthly totals, the number of days in the month, and N, the number used for truck selection.

```
    DO 670 M = 1,NTRUCKS
    ATOTCST(M) = 0.
    BTOTCST(M) = 0.
    AMNTTIM(M) = 0.
    BMNTTIM(M) = 0.
670 APOLCST(M) = 0.
    XDAYS = 0.
    N = 0
```

F

F

Check for end of simulation.
If no. of months is not equal
to the no. of periods to be simulated
return and begin next month.

NMONTHS.EQ.NPERIODS — No → 700

Yes

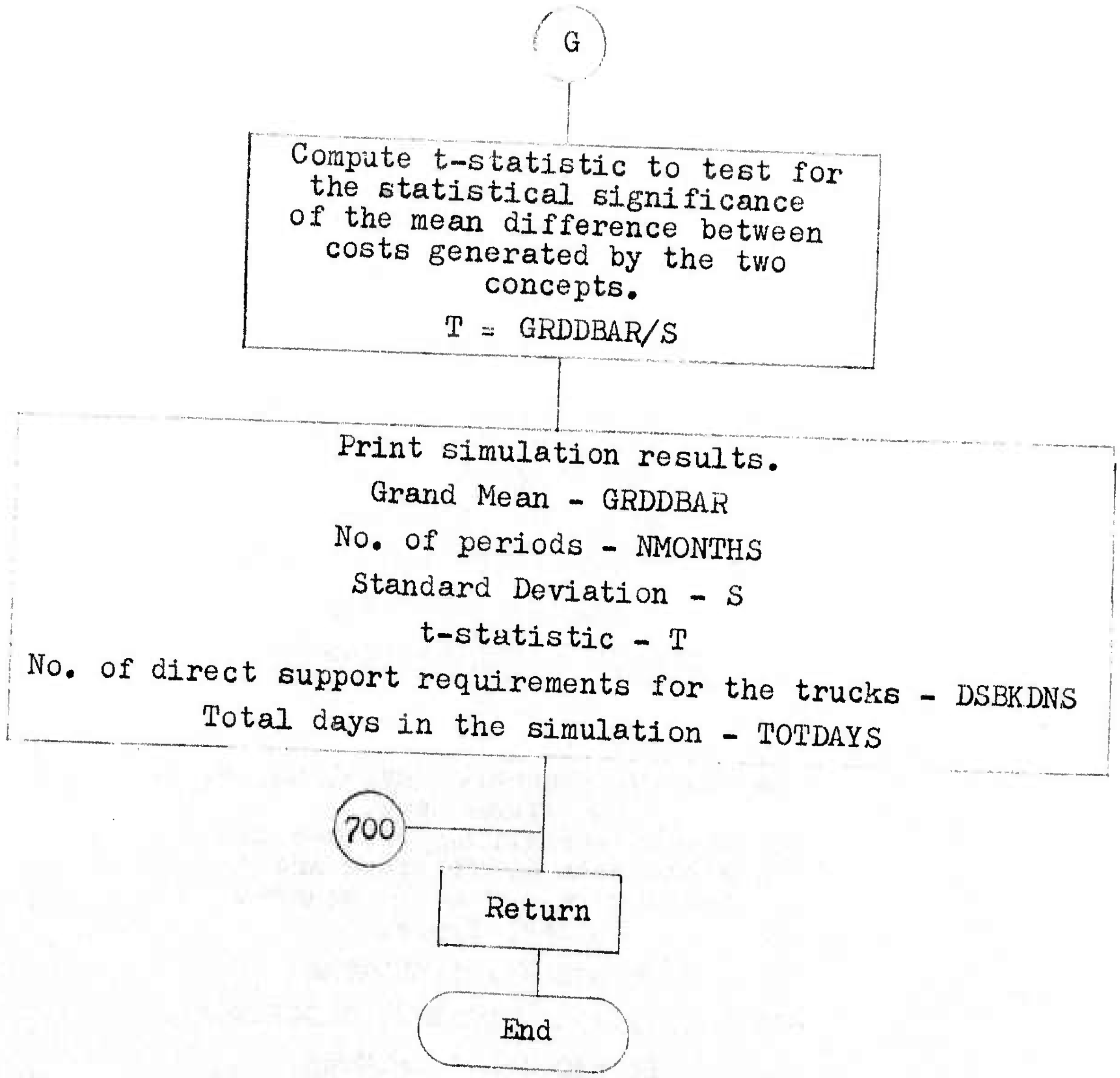
Compute simulation statistics.
Compute mean of monthly
means (grand mean).

```
    DO 600 J = 1,NMONTHS
600 SUMDBAR = SUMDBAR + DBAR(J)
    XMONTHS = NMONTHS
    GRDDBAR = SUMDBAR/XMONTHS
```

Compute the standard deviation, S, of
the grand mean.
Square deviations between the
monthly mean differences and the
grand mean. Sum the squared
deviations.

```
    DO 620 J = 1,NMONTHS
620 DEVSQR(J) = (DBAR(J)-GRDDBAR)**2
    DO 630 J = 1,NMONTHS
630 SUMDVSQ = SUMDVSQ + DEVSQR(J)
    S = SQRT(SUMDVSQ/(XMONTHS-1.))/SQRT(XMONTHS)
```

G


G
Compute t-statistic to test for the statistical significance of the mean difference between costs generated by the two concepts.
T = GRDDBAR/S
Print simulation results.
Grand Mean - GRDDBAR
No. of periods - NMONTHS
Standard Deviation - S
t-statistic - T
No. of direct support requirements for the trucks - DSBKDNS
Total days in the simulation - TOTDAYS
700
Return
End

APPENDIX C

COMPUTER PROGRAM LISTING

```
      PRØGRAM TRUKSIM(INPUT,ØUTPUT,TAPE2)
      CØMMØN/BLK5/ØGMNTM(40),DSBKDNS
      CØMMØN/BLK1/NTRUCKS,ISEED,SPTMIS,NPERIØD,XDAYS,NMØNTHS
      CØMMØN/BLK2/AMNTTIM(40),APØLCST(40),ATØTCST(40)
      CØMMØN/BLK3/BMNTTIM(40),BTØTCST(40)
      CØMMØN/BLK4/N
      CØMMØN/BLK6/BPØLCST(40)
      CØMMØN/BLK7/PØLCPM1,PØLCPM2
      CØMMØN/BLK8/TØTDAYS
      DATA NTRUCKS,ISEED,SPTMIS,NPERIØD/28,37,100.,12/
      DATA PØLCPM1,PØLCPM2/.376,.041/
      CALL RANSET(ISEED)

C   SELECT TRUCK.

   01   N=N+1
      IF(N.EQ.NTRUCKS+1)GØ TØ 25

C GENERATE BREAKDØWN.  USE INHERENT RELIABILITY ØF .98 FØR
C M151A1.  IF RANDØM NØ. IS < .02, UNSHED MAINT REQ EXISTS.
C SEE P. 70, SAMPLE DATA CØLLECTIØN REPØRT.
   03 R=RANF(A)
      IF (R.LE..02) GØ TØ 05
      GØ TØ 01

C DETERMINE IF DS ØR ØRG MAINT REQ. P(DS)=408/6995. P. 21,SDC.
C IF NØT DS, GENERATE ØRGANIZATIØNAL MAINTENANCE TIME. RETURN TØ
C SELECT NEXT TRUCK.
   05 R=RANF(A)
       IF(R.LE..0583)GØ TØ 10
      ØGMNTM(N) = ØGMNTM(N) + ØTSKTM(DUMMY)
      GØ TØ 01

C SELECT CØMPØNENT FØR DS REPAIR.
C P(ENGINE)=.1936, P(TRANSM/TRANSFER)=.3064, P(CLUTCH)=.3284,
C P(STEERING GEAR ASSEMBLY)=.0049, P(ØTHER)=.1667

   10  ASSY = RANF(A)
      DSBKDNS=DSBKDNS+1.
      IF(ASSY.LE..1936)GØ TØ 12
      IF(ASSY.GT..1936.AND.ASSY.LE..5000)GØ TØ 13
      IF(ASSY.GT..5000.AND.ASSY.LE..8284)GØ TØ 14
      IF(ASSY.GT..8284.AND.ASSY.LE..8333)GØ TØ 15
      DSMNTM = ØTHER(DUMMY)
      GØ TØ 16
   12  DSMNTM = ENGINE(DUMMY)
      GØ TØ 16
   13  DSMNTM = TRANSM(DUMMY)
      GØ TØ 16
   14  DSMNTM = CLUTCH(DUMMY)
      GØ TØ 16
   15 DSMNTM = STEERG(DUMMY)
      GØ TØ 16
```

```
C COMPARE COST OF DS REPAIR UNDER CURRENT CONCEPT AND PROPOSED
C ALTERNATIVE.
C RETURN TO SELECT NEXT TRUCK FOR DAY.

 16     CALL CURRENT(DSMNTM,SPTMIS)
        CALL PROPOSD(DSMNTM)
        IF(N.LE.NTRUCKS)GO TO 01


C ON COMPLETION OF ALL TRUCKS, ADD 1 TO NUMBER OF DAYS IN MONTH.
C ADD 1 TO TOTAL DAYS IN SIMULATION.

 25     XDAYS=XDAYS+1.
        TOTDAYS=TOTDAYS + 1.


C CHECK FOR ANY REMAINING TRUCKS. IF N > NO. OF TRUCKS AND MONTH
C NOT OVER, SET N=0 AND RETURN TO START NEXT DAY.

        IF(N.GT.NTRUCKS.AND.XDAYS.LT.21)N=0


C CHECK FOR COMPLETION OF MONTH (21 WORKING DAYS).

        IF(XDAYS.LT.21)GO TO 01
        IF(XDAYS.GT.21)PRINT*,"ERROR"
        CALL STATSUM
        IF(NMONTHS.NE.NPERIOD)GO TO 01
        CONTINUE
        END
        FUNCTION OTSKTM(DUMMY)


C TASK TIME FOR ORGANIZATIONAL MAINTENANCE.  DEFINES MIN AND MAX TIME.
C NORMAL DISTN.

  100    U1 = RANF(A)
        U2 = RANF(A)
        RNORM = (-2.0 * ALOG(U1))**0.5 * COS(2.*3.1416*U2)
  101    OTSKTM = RNORM + 1.6
        IF(OTSKTM.GT.12.2)OTSKTM = 12.2
        RETURN
        END
```

```
      FUNCTIØN ØTHER(DUMMY)

C TASK TIME FØR ALL ØTHER DIRECT SUPPØRT MAINTENANCE TASKS.
C DEFINES MIN AND MAX TIMES. EXPØNENTIAL DISTN.

      XMU = 1./10.0
      EXPTIM = (-1./XMU)*ALØG(RANF(A))
      ØTHER = EXPTIM
      IF(ØTHER.LT.1.)ØTHER = 1.
      IF(ØTHER.GT.30.)ØTHER = 30.
      RETURN
      END
      FUNCTIØN ENGINE(DUMMY)

C ENGINE REPLACEMENT TIME. DEFINES MIN AND MAX TIMES. EXPØNENTIAL
C DISTRIBUTIØN.

      XMU=1./9.5
      EXPTIM = (-1./XMU)*ALØG(RANF(A))
      ENGINE = EXPTIM
      IF(ENGINE.LT.7.)ENGINE = 7.
      IF(ENGINE.GT.19.)ENGINE = 19.
      RETURN
      END
      FUNCTIØN TRANSM(DUMMY)

C TRANSMISSIØN REPLACEMENT TIME. DEFINES MIN AND MAX TIMES.
C EXPØNENTIAL DISTN.

      XMU=1./6.7
      EXPTIM = (-1./XMU)*ALØG(RANF(A))
      TRANSM = EXPTIM
      IF(TRANSM.LT.5.5)TRANSM = 5.5
      IF(TRANSM.GT.13.4)TRANSM = 13.4
      RETURN
      END
      FUNCTIØN CLUTCH(DUMMY)

C CLUTCH REPLACEMENT TIME. DEFINES MIN AND MAX TIME. EXPØNENTIAL DISTN.

      XMU=1./4.2
      EXPTIM = (-1./XMU)*ALØG(RANF(A))
      CLUTCH = EXPTIM
      IF(CLUTCH.LT.3.5)CLUTCH = 3.5
      IF(CLUTCH.GT.8.4)CLUTCH = 8.4
      RETURN
      END
```

```
      FUNCTION STEERG(DUMMY)

C STEERING GEAR ASSEMBLY REPLACEMENT TIME. DEFINES MIN AND MAX TIMES.
C EXPONENTIAL DISTN.

      XMU=1./5.5
      EXPTIM = (-1./XMU)*ALØG(RANF(A))
      STEERG = EXPTIM
      IF(STEERG.LT.4.75)STEERG = 4.75
      IF(STEERG.GT.11.)STEERG = 11.
      RETURN
      END
      SUBRØUTINE CURRENT(DSMNTM,SPTMIS)

C MØNTHLY DS MAINT CØSTS UNDER CURRENT CONCEPT.

      CØMMØN/BLK2/AMNTTIM(40),APØLCST(40),ATØTCST(40)
      CØMMØN/BLK4/N
      CØMMØN/BLK7/PØLCPM1,PØLCPM2
      XMU=1./8.0

C GENERATE TIME TO ACCØMPLISH ALL ØRGANIZATIØNAL MAINTENANCE AS
C BY TM 38-5, LØGISTICS MAINTENANCE MANAGEMENT, PRIØR TØ ACCEPTANCE
C BY DIRECT SUPPØRT UNIT (DSU).

      ØGPRPTM=(-1./XMU) * ALØG(RANF(A))
      IF(ØGPRPTM.GT.30.)ØGPRPTM=30.

C GENERATE TRANSPØRTATIØN TIME TØ AND RETURN FRØM DSU ASSUMING USE ØF
C WRECKER. GENERATE TRANSPØRTATIØN TIME TØ PICK UP VEHICLE FRØM DSU
C USING ØNE 1/4 TØN TRUCK TØ GØ TØ DSU AND RETURN USING BØTH WHICH
C REQUIRES TWØ ØPERATØRS.

      TØTIM1=(.75 * SPTMIS/25.) + (RANF(A) * SPTMIS/25.)
      TØTIM2=(.75 * SPTMIS/25.) + (RANF(A) * SPTMIS/25.)
      FRMTIM1=(.75 * SPTMIS/25.) + (RANF(A) * SPTMIS/25.)
      FRMTIM2=(.75 * SPTMIS/25.) + (RANF(A) * SPTMIS/25.)
      TRANSTM=2. * (TØTIM1 + TØTIM2) + 2. * (FRMTIM1 + FRMTIM2)

C TØTAL TIME = ØRGANIZATIØNAL TIME + TRANSPØRT TIME + DS MAINT TIME.

      TØTTIM = ØGPRPTM + TRANSTM + DSMNTM

C ACCUMULATE TØTAL TIME FØR EACH TRUCK.

      AMNTTIM(N) = AMNTTIM(N) + TØTTIM
```

```
C COMPUTE PETROLEUM, OIL, LUBE (POL) COSTS FOR EACH TRUCK.
C SPTMIS = DISTANCE TO DSU.
C POLCPM1 = POL COST PER MILE FOR WRECKER. SEE DATA, LINE 225.
C POLCPM2 = POL COST PER MILE FOR 1/4 TON. SEE DATA, LINE 225.

      TOCOST = SPTMIS * POLCPM1 * 2.
      FRMCOST = 3. * SPTMIS * POLCPM2
      POLCST = TOCOST + FRMCOST
      APOLCST(N) = APOLCST(N) + POLCST

C TOTAL COSTS PER VEHICLE(N) = MAINT TIME * HOURLY RATE FOR ONE MAN
C                                           + POL COST.

      ATOTCST(N) = AMNTTIM(N) * 6.48 + APOLCST (N)
      RETURN
      END
      SUBROUTINE PROPOSD(DSMNTM)

C MONTHLY DS COSTS UNDER PROPOSED CONCEPT.

      COMMON/BLK3/BMNTTIM(40),BTOTCST(40)
      COMMON/BLK4/N
      COMMON/BLK6/BPOLCST(40)

C NO ORG PREP TIME OR TRANSPORTATION TIME REQUIRED TO ACCEPT VEHICLE.
C THEREFORE, ONLY DIRECT DS MAINT TIME RECORDED.

      TOTTIM = DSMNTM
      BMNTTIM(N) = BMNTTIM(N) + TOTTIM

C NO POL COST TO TRANSPORT VEHICLE TO DS MAINT LOCATION.

      BPOLCST(N)=0.

C COMPUTE TOTAL MONTHLY COST PER VEHICLE.

      BTOTCST(N) = BMNTTIM(N) * 6.48 + BPOLCST(N)
      RETURN
      END
```

```
      SUBRØUTINE STATSUM

C MØNTHLY AND SIMULATIØN STATISTICS TØ CØMPARE CØNCEPTS.

      DIMENSIØN DIFF(40),DBAR(120),DEVSQR(120)
      DIMENSIØN ATIMCST(40),BTIMCST(40),ATØTIME(40),BTØTIME(40)
      DIMENSIØN ATØTPØL(40),BTØTPØL(40)
      CØMMØN/BLK1/NTRUCKS,ISEED,SPTMIS,NPERIØD,XDAYS,NMØNTHS
      CØMMØN/BLK2/AMNTTIM(40),APØLCST(40),ATØTCST(40)
      CØMMØN/BLK3/BMNTTIM(40),BTØTCST(40)
      CØMMØN/BLK4/N
      CØMMØN/BLK5/ØGMNTM(40),DSBKDNS
      CØMMØN/BLK6/BPØLCST(40)
      CØMMØN/BLK8/TØTDAYS

      NMØNTHS = NMØNTHS + 1

C CØMPUTE DIFFERENCES IN MAINTENANCE CØST PER TRUCK FØR EACH
C CØNCEPT.

      DØ 400 K=1,NTRUCKS
 400  DIFF(K) = ATØTCST(K) - BTØTCST(K)

C SUM DIFFERENCES PER TRUCK.

      DØ 500 L=1,NTRUCKS
 500   SUMDIFF=SUMDIFF + DIFF(L)
      XTRUCKS = NTRUCKS

C CØMPUTE AVERAGE CØST PER TRUCK FØR THEMØNTH AND STØRE.

      DBAR(NMØNTHS) = SUMDIFF/XTRUCKS

      SUMDIFF=0.

C SUM MØNTHLY TØTAL CØSTS, TIME AND PØL CØSTS.

      DØ 650 M=1,NTRUCKS
      ATIMCST(M)=ATIMCST(M)+ATØTCST(M)
      BTIMCST(M)=BTIMCST(M)+BTØTCST(M)
      ATØTIME(M)=ATØTIME(M)+AMNTTIM(M)
      BTØTIME(M)=BTØTIME(M)+BMNTTIM(M)
      ATØTPØL(M)=ATØTPØL(M)+APØLCST(M)
 650  BTØTPØL(M)=BTØTPØL(M)+BPØLCST(M)
```

```
C REINITIALIZE MØNTHLY TØTALS.
      DØ 670 M=1,NTRUCKS
      ATØTCST(M)=0.
      BTØTCST(M)=0.
      AMNTTIM(M)=0.
      BMNTTIM(M)=0.
 670   APØLCST(M)=0.
      XDAYS = 0.
      N = 0


C CHECK FØR END ØF SIMULATIØN.  IF NØT END, BEGIN NEXT MØNTH.

      IF(NMØNTHS.NE.NPERIØD)GØ TØ 700
C CØMPUTATIØN ØF MEAN ØF MØNTHLY MEANS FØR THE SIMULATIØN
C PERIØD.

C SUM MØNTHLY MEANS.

      DØ 600 J=1,NMØNTHS
 600   SUMDBAR = SUMDBAR + DBAR(J)

C CØMPUTE MEAN ØF MEANS (GRAND MEAN).

      XMØNTHS = NMØNTHS
      GRDDBAR = SUMDBAR/XMØNTHS

C SQUARE DEVIATIØNSBETWEEN ØBSERVED AND MEAN DIFFERENCES.

      DØ 620 J=1,NMØNTHS
 620    DEVSQR(J) = (DBAR(J) - GRDDBAR)**2
      DØ 630 J=1,NMØNTHS
 630    SUMDVSQ = SUMDVSQ + DEVSQR(J)


C PRINT SIMULATIØN TØTALS.

 2001 FØRMAT(1X,7HVEHICLE,5X,7HATØTIME,5X,7HBTØTIME,5X,7HATØTPØL,5X,7HBT

     2ØTPØL,5X,7HATIMCST,5X,7HBTIMCST///)
 2004 FØRMAT(3X,I2,6X,6(F11.2,1X)//)
      PRINT(2,2001)


      DØ 660 I=1,NTRUCKS
 660  PRINT(2,2004)I,ATØTIME(I),BTØTIME(I),ATØTPØL(I),BTØTPØL(I),
     2ATIMCST(I),BTIMCST(I)
```

```
C COMPUTE STANDARD DEVIATION OF GRAND MEAN.

      S = SQRT(SUMDVSQ/(XMONTHS - 1.))/SQRT(XMONTHS)

C COMPUTE "T" STATISTIC TO TEST FOR STATISTICAL SIGNIFICANCE
C OF MEAN DIFFERENCE.

      T = GRDDPAR/S

C PRINT GRAND MEAN, MONTHS, STD DEV, AND "T" STATISTIC.

      PRINT 680, GRDDPAR,IMONTHS,S,T
 680    FORMAT(1H1,13HGRAND MEAN = ,F16.4///
     2,1X,9HMONTHS = ,I6///,1X,10HSTD DEV = ,F16.4///,1X,9HT STAT = ,
     3F16.4)
      PRINT*," DS BREAKDOWNS = ",DSBKDNS
      PRINT*," TOTAL DAYS IN SIMULATION = ",TOTDAYS
 700   RETURN
      END
```